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Influence of multiplied twisting process on ply yarn properties.

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ANOTATION

Influence of multiplied twisting process on ply yarn properties. Parameters of main ply yarns properties (stress-strain parameters, tensile strength, elongation, parameters and characteristically functions of mass irregularity).

Abstract

In textile, yarns have different properties that depend on the fibre used. With the structure of the yarn depending on the number of fibres in the cross section, fibre disposition and twist.

The aim of these study is to investigate or research on technology two for one twisting frame and theoretical relations between main properties of twisted and single yarn. Further to realize measurement of parameters of main ply yarn properties (stress-strain parameters, tensile strength, elongation, parameters and characteristically functions of mass irregularity) in dependence on sort of ply yarns (two, three, four ply yarns) on the ply twist. Realization of mathematical statistical evaluation and determining optimum levels of parameters of experimental yarns prepared by means of double twisting technology.

Yarns that were used in these research was 100 % cotton. Mass irregularity of yarn were analyzed using uster tester four according to ISO 16549:2004, capacitance method and standard CSN 800706 . While elongation and tenacity were investigated using Instron machine according to CSN 800700 standard.

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Nomenclature

Z	Twist of yarn [1/m]
T	Fineness [g/km]
v	Volume [cm^3]
ρ	Density [kg/m^3]
∂	Twist take up
s	Area of a cross section
μ	Packing density
CV	Square mass irregularity [%]
U	Linear mass irregularity [%]
CV_{lim}	Limit square mass irregularity [%]
U_{lim}	Limit mass irregularity [%]
I	Index irregularity [%]
CVef	Measured (actual) value of irregularity [%]
L	Length [m]
n	Number of fibres in the cross section
L_1	Instantaneous length [m]
L_o	Initial length [m]
N	Number of measurement
σ	Stress [F/A]
F	Force [N]
A	Area [m^2]
ϵ	Strain
$\overline{X}$	Mean

S	Standard deviation
CI	Confidence interval
V	Coefficient of variation

1. Introduction

A yarn is a strand composed of fibres, filaments (individual fibres of extreme length), or other material, either natural or man made, suitable for use in the construction of interlaced fabrics such as woven or knitted types. The strand may consist of a number of fibres twisted together, a number of filaments grouped together but not twisted or a number of filaments twisted together. A single filament called monofilament, it is with twist or no twist. These properties of yarn employed greatly influence their appearance, texture and its performance. [1]

A plied yarn is one where multiple strands of yarn - already spun yarn are put together and twisted in the opposite direction from that in which they were first twisted. A two ply yarn has two strands and three ply yarn has three. Any time when a yarn is plied is to make it stronger. This is because twist adds strength, multiple directions of twist add even more strength. Also tucking some of the surface of the yarn inside, away from the elements, wear and tear. For some applications, they also bring the benefit of counteracting twist energy in the single yarns, such that plying can eliminate the risk of bias or skew in certain types of yarn uses like knitting. Plying can also even out unevenness in single yarns, changes how the yarn behave and feel. Many two ply yarns are used in carpet, in cut pile carpet for example Saxony. Plied yarns must be heat set to prevent untwisting under traffic. [1]

Fibres that are suitable for textile use processes adequate length, fineness, strength, how the yarn is flexible, fabric construction and the use of a completed fabric. some of the properties affecting textile fibre performance include elasticity, crimp (waviness), moisture absorption, reaction to heat and sunlight. [1]. The main properties of fibres are fineness, length and their density, thermal properties, reaction to moisture. Also tensile properties, thermo mechanical responses, fibre breakage, fatigue and fibre friction as other properties of fibres. [2]

Classification of yarns

- Single
- Folder

- Ply

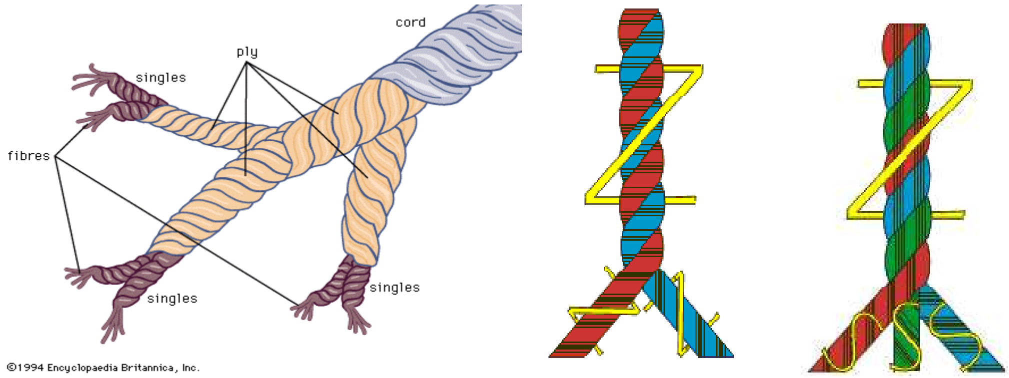

Figure 1: Pictures of plied yarns. [1] and [3]

1.1. Aim of this project is as follows:

- Analyzing technology on the two for one twisting frame and theoretical relation between main properties of twisted and single yarns.
- Proposal of experiment for determining of ply twist influence and single yarns number in ply yarn influence on the selected properties of ply yarn.
- Realization of measurement of parameters of main ply yarns properties (stress strain parameters – tensile strength, elongation, parameters and characteristics function of mass irregularities) in dependence on sort of ply yarns (two, three, four ply yarns) and on the ply twist.
- Realization of mathematical statistics evaluation and determination of optimum levels of parameters of experimental yarns prepared by means of double twisting technology.

2. Literature review

2.1. Single yarn

A single yarn is the same as ply, yarns with single strands are composed of fibres held together by at least a small amount of twist, or of filaments grouped together either with or without twist or of narrow strips of material. It can be a single man made filament extruded in sufficient thickness for use alone as yarn. [1]

The characteristics of a yarn are strongly dependent upon the characteristics of its fibres, but they are equally dependent upon the structure of the yarn itself. [4]

These are the factors:

(a) The number of fibres in the yarn cross-section

(b) Fibre disposition

(c) Fibre alignment

(d) Position of the fibres in the strand

(e) Twist. [4]

2.2. Twisted yarn

Twist plays an important role in affecting the arrangement of fibres or filaments in the yarn cross section. In staple yarns, twist is essential to hold the fibres together and to impart some degree of cohesiveness to the structure. On the other hand, the filaments in a multifilament yarn would fray away if there were no cohesive forces holding them together. Furthermore, the formation of plied or cabled yarns is also achieved by twisting single or oiled yarns together to produce a coherent linear structure. In other words, twist is a means by which a bundle of fibres, filaments, or yarns in a plied yarn is held together so that the ultimate structure is made capable of withstanding the stresses, strains and the chafing action of the many processes involved in the manufacture and use of textile fabrics. [6]

When a number of components (fibres or filaments) in a continuous strand are twisted, radial forces develop which in turn affect the relative position of the components in the yarn structure, leading to a close packing of all components in a given cross section. Thus the insertion of twist in fibre assemblies (yarns) affects, in addition to the tensile properties (strength-extension, the diameter and the specific volume in other words, softness or hardness) of yarns. The change in the fibre packing in turn determines the cover of a fabric and such other properties as warmth, crease recovery, permeability and various other related characteristics. Twist also affects the hairiness of yarns, which is a very important property in determining the pilling behavior and economics of the singeing process. [6]

2.2.1. Definition of twist

When two end of a straight strand (yarn) are rotated relative to one another, the fibres on the surface of the yarn lie in the helices about the yarn axis. In other words, a yarn is twisted when fibres on the surface, which were originally parallel to the axis of the yarn, are now deformed (rotated) so that they make an angle θ with the axis. These definition applies only to the ideal case of an originally straight fibre assembly. However, in actual yarns, variability of yarn diameter, contraction because of twist, migration of fibres from one zone to the other radial compression of the yarn and fibre slippage are some of the factors that tend to make the yarn geometry depart from the ideal. [6]

2.2.2. Direction of twist

In the designation of yarn, it is essential to specify the direction of twist.

The direction of twist in a yarn is designated:

a. Right-hand twist. S twist or clockwise.
b. Left-hand twist. Z twist or anticlockwise.

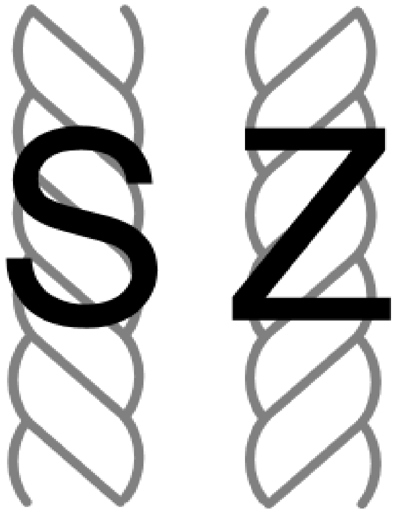

Figure 2: Twist direction. [6]

Relation between amount of twist and strength.

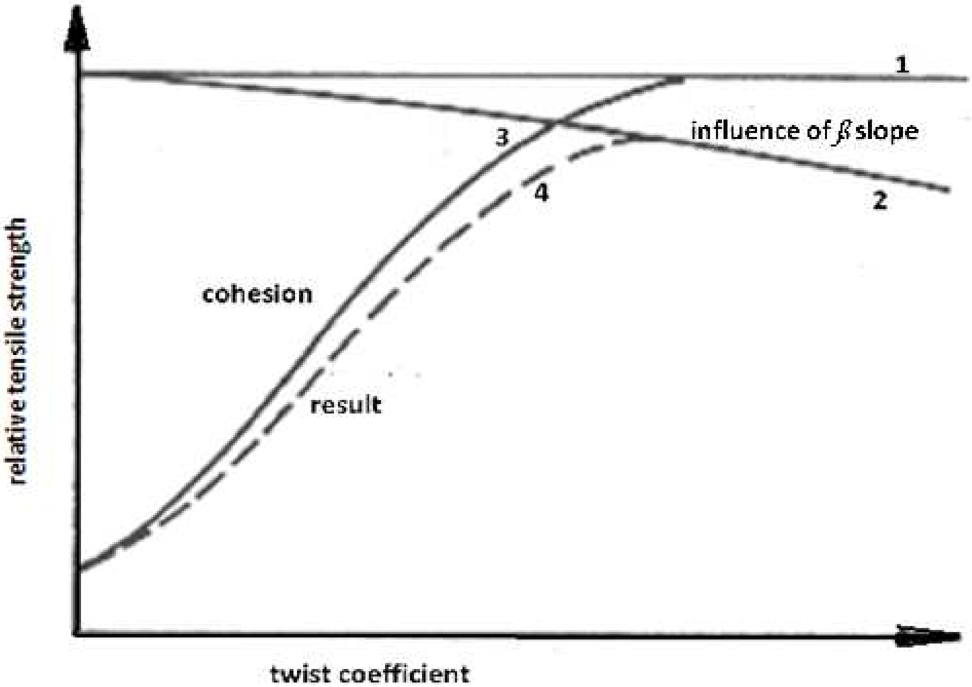

Figure 3: dependence of twist on strength. [5]

Twist can be calculated as follows:

Koechlin's formula – this formula is derived from helix model.

For single yarn [4] : $Z = \alpha * \frac{31.623}{\sqrt{T_{tex}}}$ (1)

For ply yarn [5] : $Z_p = \alpha_p * \frac{31.623}{\sqrt{n * T_{tex}}}$ (2)

Phrix's formula [5] : $Z = \alpha_n * \frac{100}{\sqrt[3]{{T_{tex}}^2}}$ (3)

this formula is suitable for spinning twist only.

2.3. Fineness

Fineness determines how many fibres are present in the cross-section of a yarn of a given thickness. Fibre fineness influences yarn strength, yarn evenness and drape of the fabric product. [4]. It is defined as mass (weight) counting. System tex – it means how many grams does one kilometer of fibrous product weigh basic unit [10] :

$$T\ [tex] = \frac{m\ [g]}{l\ [km]} \qquad (4)$$

$$T_{tex} = \frac{v\rho}{l} \qquad (5)$$

2.3.1. Fineness of a double yarn- $T_D[tex]$

Double yarn is formed by means of winding of two or more single yarn together on one bobbin.

Fineness of doubled yarn is expressed as a sum of all single yarns count [5] :

$$T_D = \sum_{i=1}^{N} T_i \qquad (6)$$

When $T_1 = T_2 = T_3 = ...T_n = T_1$ then we can write: $T_D = n * T$

2.3.2. Fineness of ply yarn - $T_p[tex]$

Twist take up (∂) is expressed as specific shortening of twisted yarn compared to the single yarn [5]:

.

$$\partial = \frac{L - L_s}{L} * 100[\%] \qquad (7)$$

General formula

$$T_p = \sum_{i=1}^{n} T_i * \frac{100}{100 - \partial_1}[tex] \qquad (8)$$

If Fineness of all twisted yarn are the same [5]:

$$T = T_1 = T_2 = \ldots\ldots\ldots\ldots.. T_i, \partial = \partial_1 = \partial_2 = \ldots\ldots\ldots\ldots\ldots\ldots\ldots \partial_i$$

we can write:

$$T_s = n * T * \frac{100}{100 - \partial}[tex] \qquad (9)$$

2.4 Fibre elongation

Breaking elongation – the maximum possible extension of the fibre until it breaks for example the permanent elongation and elastic elongation together [5]:

$$elongation = \frac{l_1 - l_2}{l_2} * 100 \qquad (10)$$

There are three types of elongation:

(a) Permanent elongation – that part of the extension through which the fibre does not return on relaxation.

(b) Elastic elongation – that part of the extension through which the fibre does return.

(c) Viscoelastic elongation. [4]

2.5. Tensile strength

2.5.1. Three definitions of tensile strength

Yield strength- the stress at which material strain changes from elastic deformation to plastic deformation, causing it to deform permanently.

Ultimate strength – the maximum stress a material can withstand when subjected to tension, compression or shearing. It is the maximum stress on the stress-strain curve.

Breaking strength – the stress coordinate on the stress strain curve at the point of rupture. [11]

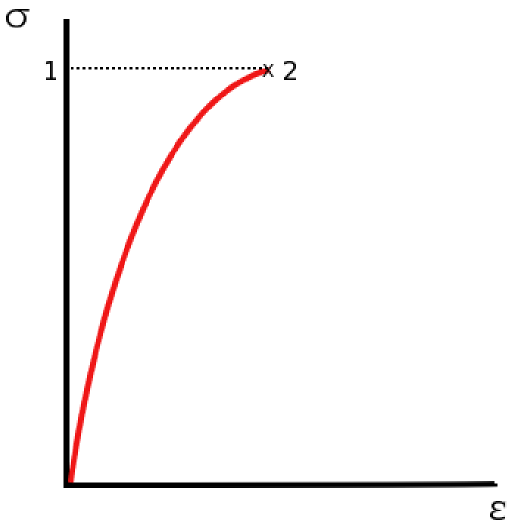

Figure 4: stress-strain curve – dependence between strength and elongation. [11]

Where 1. Ultimate strength

2. Rupture

Tensile strength is the stress at which a material breaks or permanently deforms. It is an intensive property and consequently does not depend on the size of the test specimen. It dependent on the preparation of the specimen and the temperature of the test environment and material. Tensile strength along with elastic modulus and corrosion resistance, is an important parameter of engineering materials that are used in structure and mechanical devices. It is specified for materials such as alloys, composite materials, ceramics, plastics and woods. [11]

2.6. Mass irregularities (Mass unevenness)

Mass irregularity (mass uneveness) is a variation of fibre mass in the cross-section or in some section lengths of longitudinal fibrous product.

Mass irregularity can be caused by one of the following:

(a) Random distribution of fibres

(b) Random character of fibres

(c) Faults during yarn production. [12] , [13]

Due to plying the yarn mass unevenness is influenced by [5] :

$$CVply = \frac{CV\,single}{\sqrt{N}} \tag{11}$$

The above equation can also represent the effect of doubling.

2.6.1 Types of irregularities

2.6.1.1. Weight per unit length

Variation in weight per unit length is the basic irregularity in yarn. All other irregularities are dependent on it. The reason for these is because weight per unit length is proportional to fibre number, number of fibres crossing a section of yarn. Difference in fibre number is influenced by drafting. [14]

2.6.1.2. Diameter

Variability in diameter is important because of its profound influence on appearance of yarn. Diameter is one of those parameters that is unavoidable, especially for staple yarns. Variability in diameter is important because of its influence on yarns. Diameter variability is caused by weight variability as it is known that twist has a tendency to run into thin place, these variability are exaggerated in diameter variability. [14]

Yarn diameter can be expressed in these way [10]:

$$D = \sqrt{\frac{4s}{\pi\mu}} \qquad (12)$$

And

$$D = \sqrt{\frac{4T}{\pi\mu\rho}} \qquad (13)$$

Yarn diameter is a major design criterion. Factors affecting yarn diameter are essentially those that affect yarn density or fibre compactness. Those properties are fiber fineness, fiber stiffness, fibre length and fibre crimps. Coarse and stiff fibres will result in bulkier or thicker yarn than fine and flexible fibres. These fibres becomes coarser, yarn density becomes smaller leading to an increase in yarn diameter., although the count of yarn remains unchanged. [14]

2.6.1.3. Twist

Twist variation is important because of its influence on performance of yarn and fabric dye ability and detects. Soft ends are a major cause of breaks in weaving preparatory and loom shed. Soft twisted yarns takes more dye and so uneven dyeing is caused by high twist variation. Twist variation come from slack spindle tapes and jammed spindles. [14]

2.6.1.4. Strength

Importance of strength variation is to appreciate yarn breaks at the weakest element and so yarns with high strength variability will result in high breakages in further process. Strength is dependent on count and partly upon spinning conditions and mechanical defects. Yarn strength is an important parameter comparing to the other parameters. It is used as a quality parameter of a yarn. [14]

2.6.1.5. Hairiness

High variation in hairiness leads to streaky warp way appearance and weft bars in fabric. More light will be reflected from portions of weft where hairiness is more and this leads to weft bands. High hairiness disturb warp shed movement in weaving and results in breaks, stitches and floats. [14]

It is a key parameter that affects yarn performance in the subsequent processes and degrades fabric appearance. But it is still remains a complex subject, which requires further in depth understanding. Distribution of hair length is one of the most important characteristics of the yarn. Hairiness required for further processing and to give a soft feel to the fabric. More hairiness leads to pilling and fuzzy fabric appearance. [16]

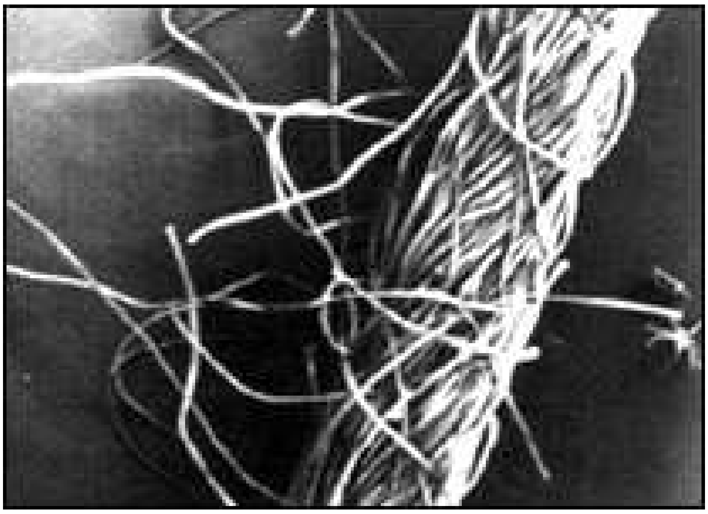

Figure 5: Picture of hairiness. [16]

2.6.1.6. Raw material

It can cause irregularities because natural fibres have variable verities (quality or condition of being true or real), no true fixed length, fineness, shape of cross-section, maturity, crimp. These have effect on yarn properties especially evenness. It can be because of cell development due to changes in environmental conditions which are nutrients, soil and weather.

In men made fibres, variation of mass per unit length occurs due to change in polymer viscosity, roughness of spinneret orifice, variation in extrusion pressure and rate, filament take up speed, presence of additives, which can modify the particular shape and fibre surface geometry.

Irregularities can adversely affect many of the properties of textile materials. The most consequence of yarn evenness is the variation of strength along the yarn. If the average mass per unit length of two yarns is equal, but one yarn is less regular than the other, it is clear that the more even yarn will be the stronger of the two. The uneven one should have more thin regions than the even one as a result of irregularity, as average linear density is the same. An irregular yarn will tend to break more easily during spinning, winding, weaving, knitting or in any process where stress is applied. Other fabric properties such as abrasion or pill-resistance, soil retention, drape, absorbency, reflectance or luster can be directly influenced by yarn evenness. By these, the effects of irregularity are widespread throughout all areas of the production and use of textiles. [14]

2.6.2. Linear mass irregularities

It expresses mean linear deviation from the mean value of mass of section length of fibrous product [12], [13] :

$$U = \frac{100}{\overline{m}L}\int_0^L \left| m(l) - \overline{m} \right| .dl \qquad (14)$$

2.6.3. Square mass irregularity

Variation coefficient of mass at the given section length. It is recommended to use the coefficient of variation exclusively for the determination of the mass evenness [12], [13] :

$$CV = \frac{100}{\overline{m}} \sqrt{\frac{l}{L} \int_0^1 (m(l) - \overline{m})^2 .dl} \qquad (15)$$

$$\frac{CV}{U} = 1.25 \qquad (16)$$

The above equation holds in the case of normal distribution of mass.

2.6.4. Limit mass irregularity

Minimum irregularity, represents the ideal case. It is caused by random distribution of fibres in the cross section of fibrous product (e.g. variation of number of fibres in the cross section) and fibre cross section variability (own fibres irregularity). It is not possible to produce the absolutely even yarn. [12], [13]

Martindale's formula for limiting irregularity calculation [12]:

$$CV_{\mathrm{lim}} = \frac{100}{\sqrt{n}} \qquad (17)$$

$$U_{\mathrm{lim}} = \frac{80}{\sqrt{n}} \qquad (18)$$

Number of fibres can be estimated from the relation [8]:

$$n = {tex_{yarn}}/{tex_{fibre}} \qquad (19)$$

Extended Martindale formulas

It respects cross-section variability of fibres [12]:

$$CV_{\lim} = \frac{100}{\sqrt{n}}\sqrt{1+\left(\frac{V_p}{100}\right)^2} \qquad (20) \qquad\qquad U_{\lim} = \frac{80}{\sqrt{n}}\sqrt{1+\left(\frac{V_p}{100}\right)^2} \qquad (21)$$

2.6.5. Index of irregularity

Shows how real fibrous product deviates from the ideal case (where I = 1). It can indicate how well a spinning machine is operating or whether this has become worse over a period of time [12], [13] :

$$I = \frac{CV_{ef}}{CV_{\lim}} \rangle 1 \qquad (22)$$

$$I = \frac{U_{ef}}{U_{\lim}} \rangle 1 \qquad (23)$$

3. Two for one twisting (TFO)

Two for one twisting (TFO), the process of twisting is an indispensable means of improving curtain yarn properties and satisfying textile requirements that cannot be fulfilled by the single yarns. The method of twisting two or more single yarns is called doubling, folding or ply twisting. Such yarns are designated as double yarn, folded yarn or plied yarn and the machines intended for the purpose are called doubles, ply twisters or two for one (TFO) twisters. [17]

Assembly winding is used to assemble two ends of yarn on one package in preparation for two-for-one twisting. It is particularly important to ensure that the two yarns are wound at the same tension. The assembly wound package remains stationary, the yarn passing through a guide mounted on a rotating arm which can freely rotate, through the hollow rotating spindle, then through an eyelet (outlet hole) and from there via a yarn guide and yarn take-up rollers to the yarn winding head. One revolution of the spindle inserts one turn of twist into the yarn while the rotating eyelet simultaneously inserts a turn of twist in the yarn in the balloon. [18]

During one revolution of spindle two turns are inserted into ply yarn. One inside the spindle, second in the balloon. To perform the functions of spindle twisting, cone winding and guiding yarn, it needs to change the motors rotation direction to get the S and Z twist, switch the gears to get different degrees of twist, apply gear and cam transmission to the to-and-fro guiding yarn. [19]

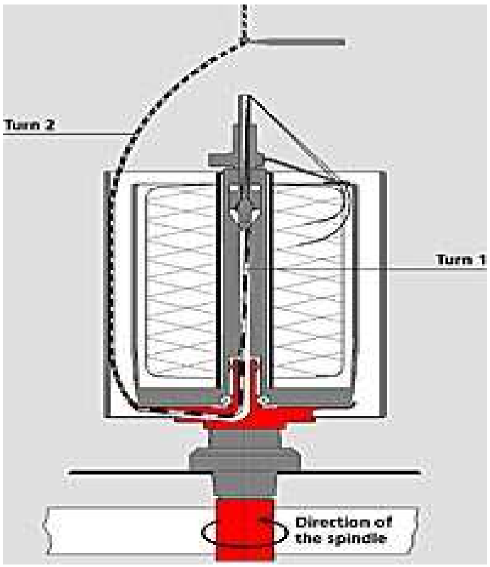

Figure 6: Two-for-one spindle. [17]

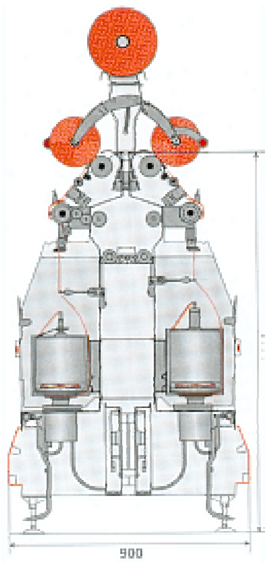

Figure 7: Two-for-one twisting machine. [17]

4. Devices used to analyze the results.

- Uster tester
- Instron

4.1. Uster tester

- The Uster tester machine uses sensors to inspect the yarn.
- Detects and classifies trash, dust particle in the yarn.
- Spectrograms allows identification of periodic faults.

4.1.1. Capacitive method

These measuring device of an electronic capacitance tester is a parallel plate capacitor. Under certain conditions a non conducting material such as a sliver or yarn is introduced between the plates to change the capacity of the capacitor. These change is proportional to the weight of material present. When the material is drawn through the capacitor continuously, the changes in the capacity will follow the variation in the weight per unit length of the strand. The unit length is the length of the capacitor. A high frequency electric field is generated in the sensor slot between a pair of capacitor plates. If these mass between plates changes, the electrical signal is altered and the output signal of the sensors changes. The results found is an electrical signal variation proportional to the mass variation of the test material passing through. These analog signal is then converted into a digital signal, stored and processed by Uster tester. [14]

Figure 8 :Uster tester machine. [20]

4.1.2. Some of the negatives or problems about the process.

- The moisture in the material affects the magnitude of the change in capacity, higher moisture content giving a greater change in capacity.
- Shape of the cross section of the tested strand affects the change in capacity. So it is necessary that the strand maintains its shape during its passage through the capacitor.
- The length of the capacitor should be as short as possible so that the variations in weight are measured over short length. [14]

4.2. Instron machine

The Instron machine evaluate the mechanical properties of materials and components using tension, compression, flexure, impact, torsion and hardness tests. Testing involves taking a small sample with a fixed cross-section area and then pulling it with a controlled, gradually increasing force until the sample changes shape or breaks. For a better results the test for each yarn has been repeated for fifty times. Force required to break the yarn or yarn extension at break were recorded. [21]

Figure 9 :Instron machine. [22]

5. Data statistics.

5.1. Average (Mean).

It has two meanings: Arithmetic mean and expected value of a random variable, which is also called the population mean. For a data set, the mean is the sum of the observations divided by the number of observation [23]:

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (24)$$

5.2. Standard deviation.

Is a widely used measure of the variability or dispersion. It shows how much variation there is from the average (mean). A low standard deviation indicates that the data points tend to be very close to mean [24]:

$$S = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2} \qquad (25)$$

5.3. Confidence interval.

Confidence interval (CI), is a particular kind of interval estimate of a population parameter. Instead of estimating the parameter by a single value, an interval likely to include the parameter is given. It is used to indicate the reliability of an estimate [5]:

$$CI = \overline{x} \pm t_{1-\frac{\alpha}{2}}(n-1)\frac{S}{\sqrt{n}} \qquad (26)$$

This is confidence interval of mean value.

Confidence interval can be also calculated using the following formula [5]:

$$CI = CV + \Delta CV \qquad (27)$$

Where $\Delta CV = \frac{2CV}{\sqrt{2\frac{\bar{L}}{l}}}$

Applied formula for reliability of one measurement (27) results from generally defined confidence interval of variation coefficient.

5.4. Coefficient of variation.

In handling large quantities of data statistically, the coefficient of variation (CV) is commonly used to define variability [14]:

$$V = \frac{S}{\bar{x}} * 100 \qquad (28)$$

6. Experimental part

6.1. Aim of the experiment

- Analyzing technology on the two for one twisting frame and theoretical relation between main properties of twisted and single yarns.
- Proposal of experiment for determining of ply twist influence and single yarns number in ply yarn influence on the selected properties of ply yarn.

- Realization of measurement of parameters of main ply yarns properties (stress strain parameters – tensile strength, elongation, parameters and characteristics function of mass irregularities) in dependence on sort of ply yarns (two, three, four ply yarns) and on the ply twist.
- Realization of mathematical statistics evaluation and determination of optimum levels of parameters of experimental yarns prepared by means of double twisting technology.

Below is a table of cotton yarns used in the experiment. Yarns were manufacture in company Hoflana Liberec – Machnín, Ltd.

– Single yarns = carded ring spun yarn
– Twisting machine – two-for-one twisting machine Alma TM 180B.

Table 1:100% cotton Nm 34 (29.5 tex).

Ply twist	Colour of tube	Two ply yarn	Three ply yarn	Four ply yarn
		Twist [m^{-1}]	Twist [m^{-1}]	Twist [m^{-1}]
-30 %	yellow	**360**	**260**	**210**
-15%	red	**440**	**320**	**250**
Standard	black	**520**	**380**	**290**
+15%	white	**600**	**440**	**330**
+30%	violet	**680**	**500**	**370**

Table 2:100% cotton Nm 20 (50tex).

Ply twist	Colour of tube	Two ply yarn	Three ply yarn	Four ply yarn
		Twist [m^{-1}]	Twist [m^{-1}]	Twist [m^{-1}]
-30 %	yellow	**265**	**140**	**170**
-15%	red	**320**	**220**	**200**
Standard	black	**375**	**300**	**230**
+15%	white	**430**	**380**	**260**
+30%	violet	**485**	**460**	**290**

Table 3:100% cotton Nm50 (20 tex).

Ply twist	Colour of tube	Two ply yarn	Three ply yarn	Four ply yarn
		Twist [m^{-1}]	Twist [m^{-1}]	Twist [m^{-1}]
-30 %	yellow	**490**	**400**	**250**
-15%	red	**590**	**480**	**310**
Standard	black	**690**	**560**	**370**
+15%	white	**790**	**640**	**430**
+30%	violet	**890**	**720**	**490**

6.2. Procedure

Measuring method

Mass irregularity was measured according to the standard ISO 16549:2004, textiles – unevenness of textiles threads – capacitance method and standard CSN 800706. The measuring speed of the uster tester, V = 400 m/min per one minutes. The number of test performed was only one measurement because of the shortage of material. These measurement was performed for all the yarns 20 tex, 29.5 tex and 50 tex. The value of humidity in the laboratory was 65 % and temperature was between (20 – 25) ^{o}C. Confidence interval was calculated according to the formula. (5b)

6.3. Analyzing of results

Graphs of Mass irregularity vs number of twist

20 tex yarn

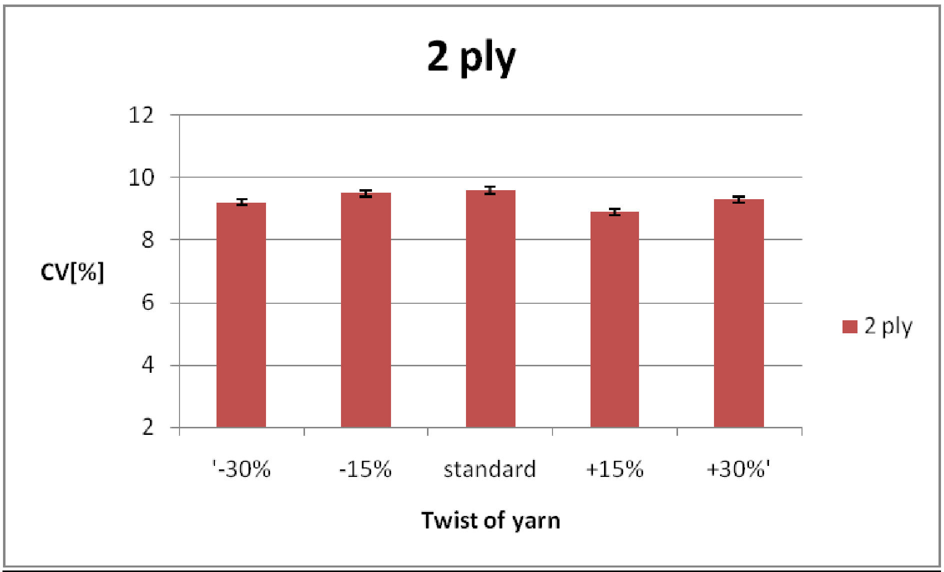

Figure 10: Mass irregularity vs twist of yarn in two ply yarn (20 Tex).

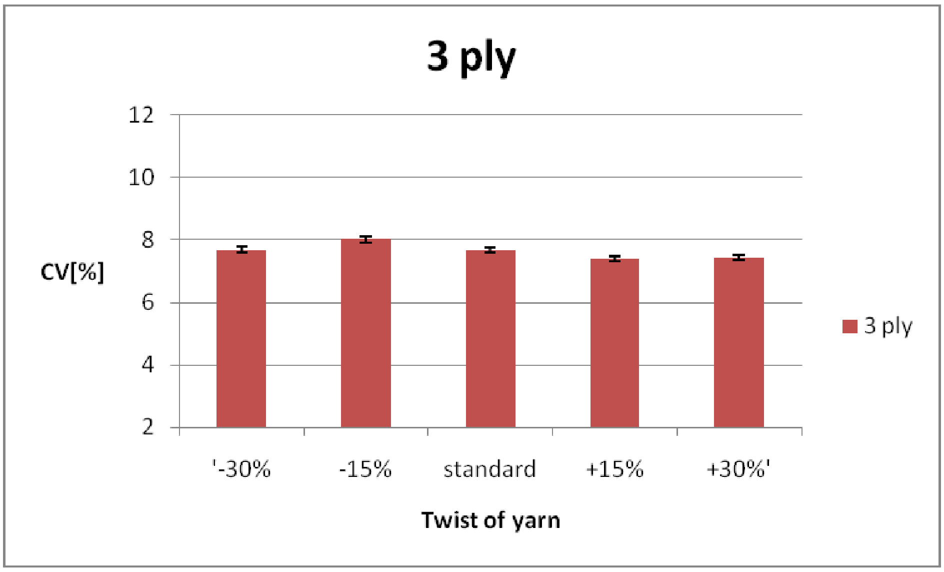

Figure 11: Mass irregularity vs twist of yarn three ply yarn (20 tex).

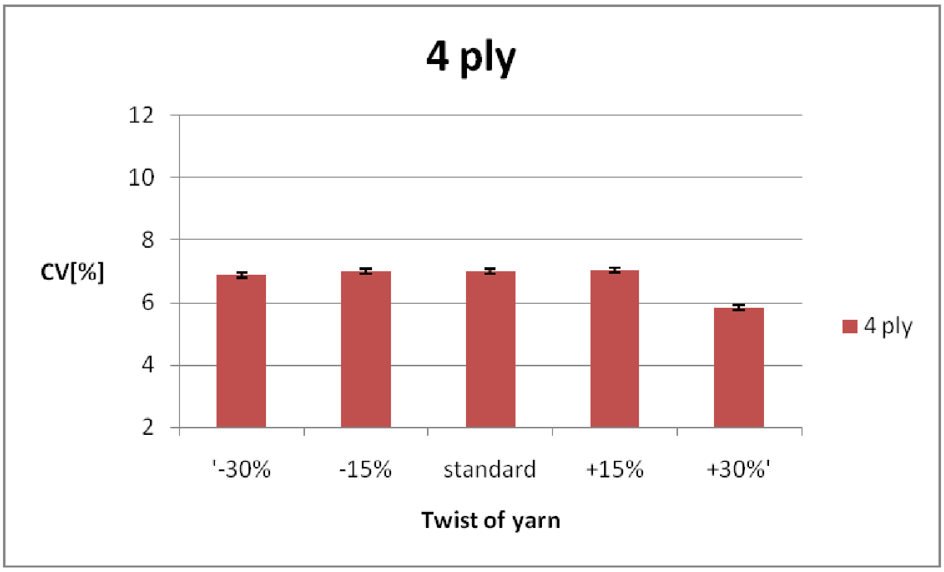

Figure 12: Mass irregularity vs twist of yarn in four ply yarn (20 tex).

In figure 10. Twist of yarn does not have any important influence in the mass irregularity of a twisted yarn. These can be seen in the graph that the standard yarn (ply yarn with standard twist number) has a higher value of mass irregularity than the other yarns including the fifteen percent yarn and the thirty percent yarn.

In figure 11. Minus fifteen percent yarn has the highest value of mass irregularity when comparing to the other yarns. It has higher twist than the minus thirty percent. Even thou the standard, fifteen and thity percent yarn has higher number of twist than the minus fifteen percent they have lower value of mass irregularity. That gives us that mass irregularity is not dependent on the twist of yarn.

In figure 12. From the graph above it has been found that mass irregularity is not depending on the number of twist. Even in a high number of twist mass irregularity can be very small. Example of these is the last yarn in the graph . It has small value of mass irregularity compared to the others even thou the number of twist is high compared to the other four. In fig 12 below, it shows that increasing the number of plying minimize irregularity.

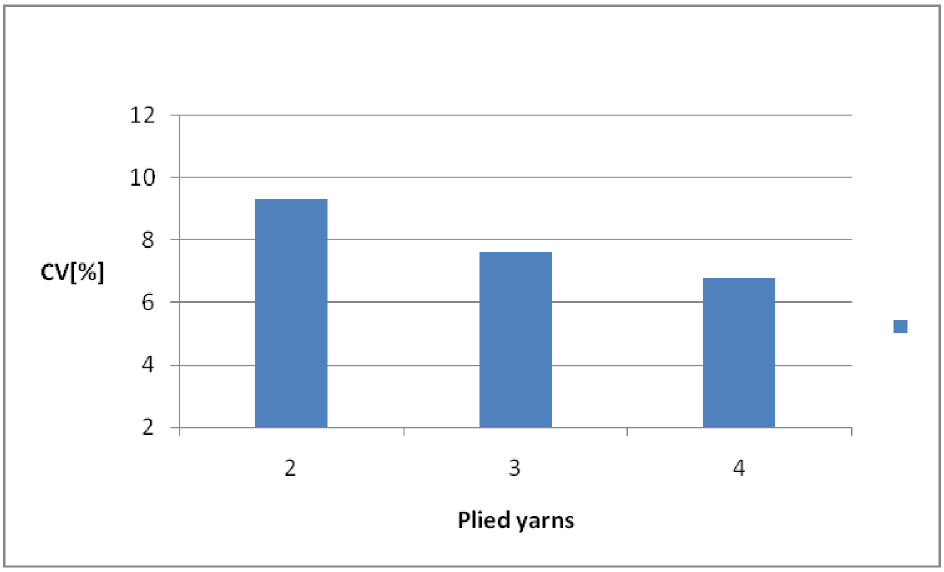

Figure 13: Mass irregularity vs two, three and four ply (20 tex).

29.5 tex yarn

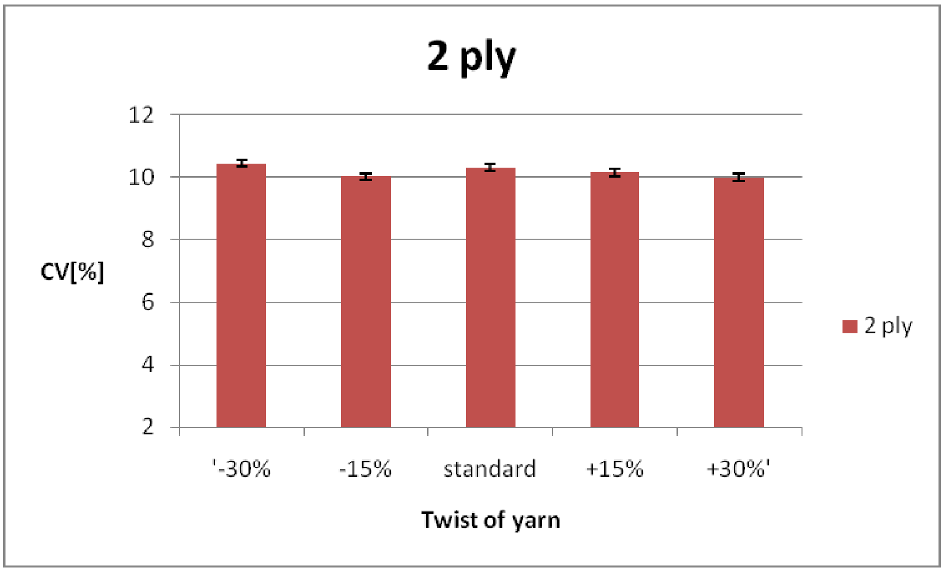

Figure 14: Mass irregularity vs twist of yarn in two ply yarn (29.5 tex).

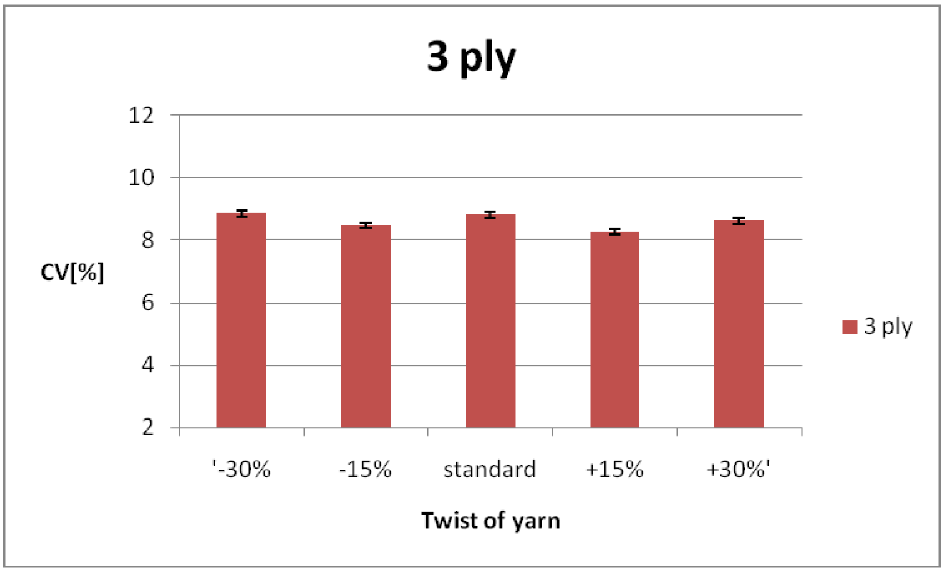

Figure 15: Mass irregularity vs twist of yarn for three ply yarn (29.5 tex).

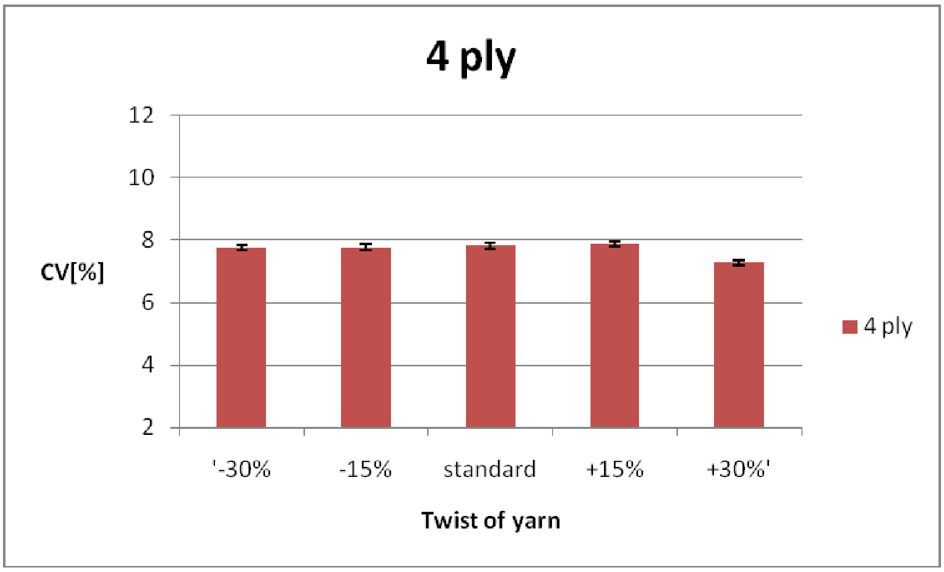

Figure 16: Mass irregularity vs twist of yarn for four ply yarn (29.5 tex).

In figure 14. It can be seen that mass irregularity is indipendent on the number of twist. In figure 15.The standard yarn has higher value of mass irregularity than the minus fifteen percent and the fifteen percent. But its value of mass irregularity is closer to minus thirty percent and the thirty percent yarn. Even thou the number of twist is increased, it does not have an effect on mass irregularity. Therefore we can conclude that mass irregularity is independent of the number of twist.

In all the three graphs (fig.14-16), two, three and four ply yarns for 29.5 tex it has been found that when plying yarns it minimize mass irregularity (see fig. 16) . It is due to yarn doubling. By this, the theoretical formula (11) has been confirmed - higher number of single yarn in ply yarn means lower CV of ply yarn. These has been showed from the graphs or results that a four plied yarn has lower value of mass irregularity than the three ply yarn to the two ply yarn. But still in these results the twist has no influence in mass irregularity, it is independent.

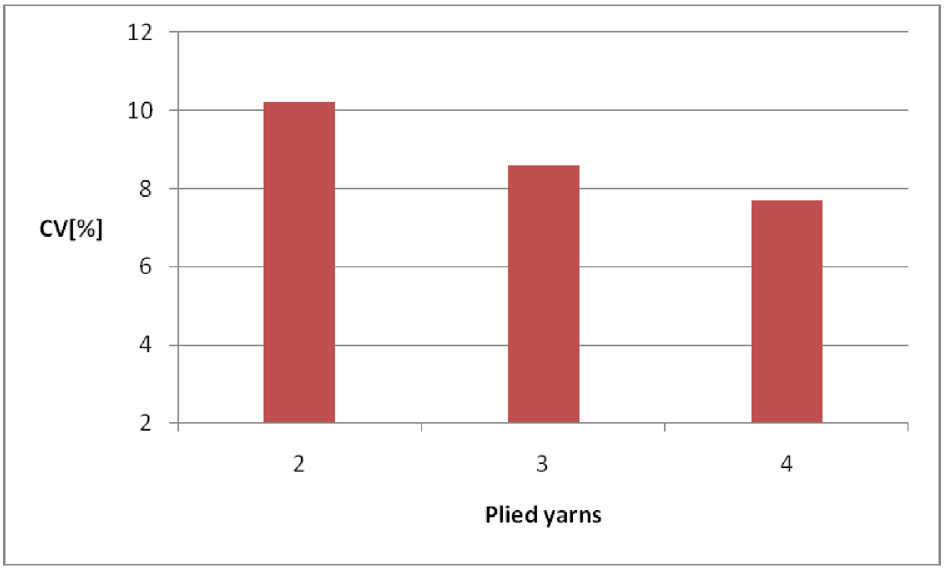

Figure 17: Mass irregularity vs two, three and four ply yarn (29.5 tex).

50 tex yarn

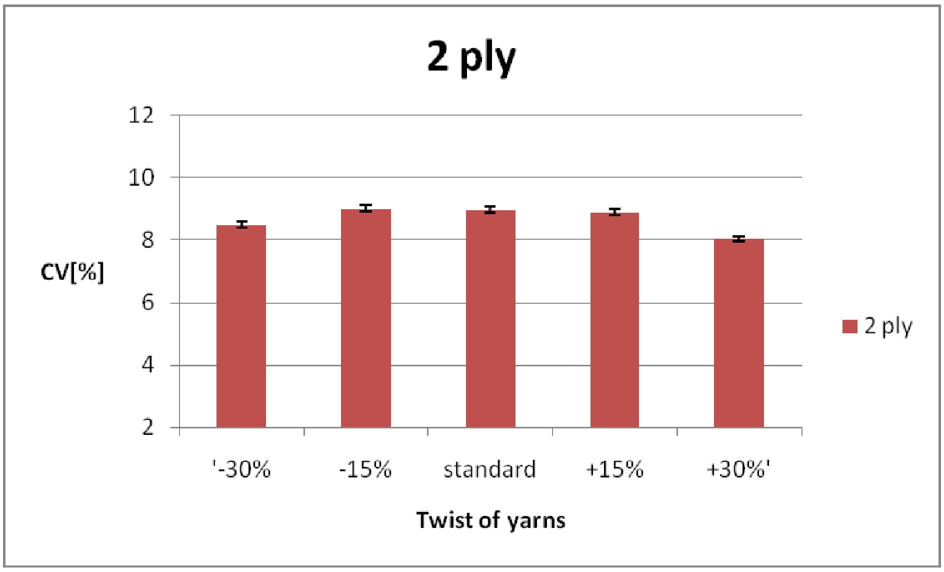

Figure 18: Mass irregularity vs twist of yarn for two ply yarn (50 tex).

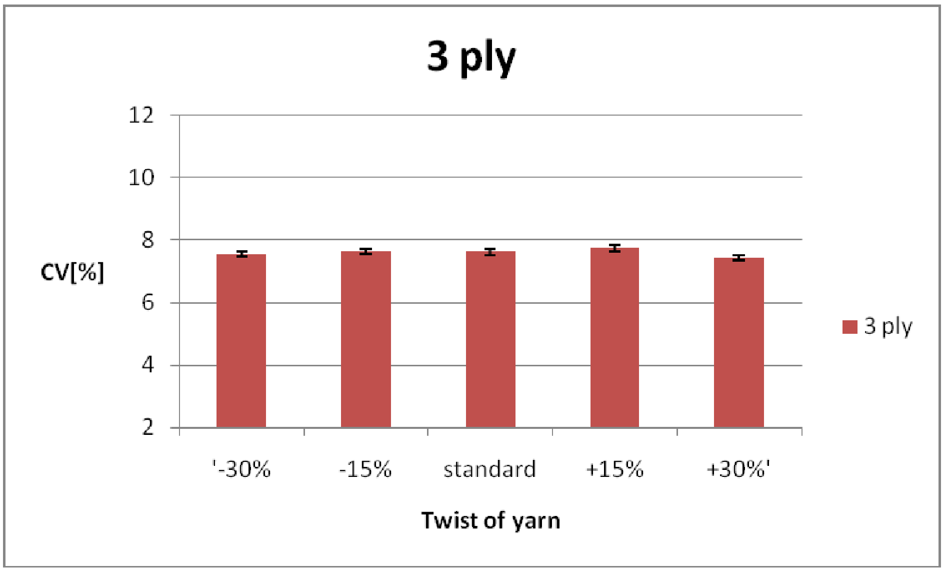

Figure 19: Mass irregularity vs twist of yarn for three ply yarn (50 tex).

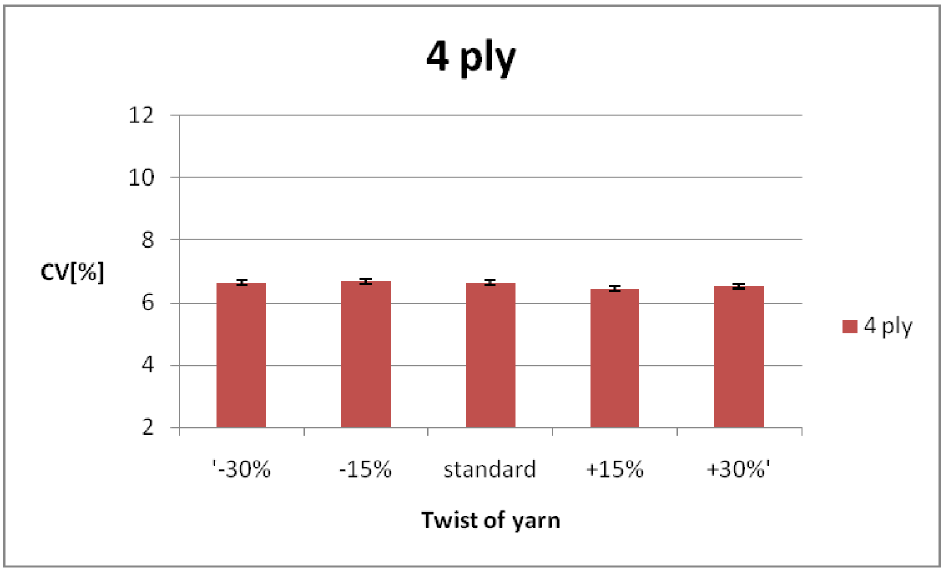

Figure 20 : Mass irregularity vs twist of yarn for four ply yarn (50 tex).

In figure 18. Middle yarns, for example minus fifteen percent yarn, standard yarn and fifteen percent yarn has high value of mass irregularity than the minus thirty percent yarn and the thirty percent yarn. It can be seen in the graph that also their confidence interval overlaps which means the difference is minimal. The thirty percent yarn has the lowest value of mass irregularity. That shows that even thou the number of twist is high the value of mass irregularity can be lower. Mass irregularity is independent on the number of twist of yarn.

In figure 19, the value of mass irregularity is lower than the value of mass irregulaity of a two ply yarn in graph number eight. In graph number eight the value of mass irregularity is above eight percent and in these graph is lower than eight percent. These shows that when increasing the number of plying in a yarn it decrease mass irregularity. Three ply yarn has a lower value of mass irregularity then the two ply yarn.

In figure 20. The results of fifty tex yarn also gives the same evidence that mass irregularity is independent on twist of yarn.

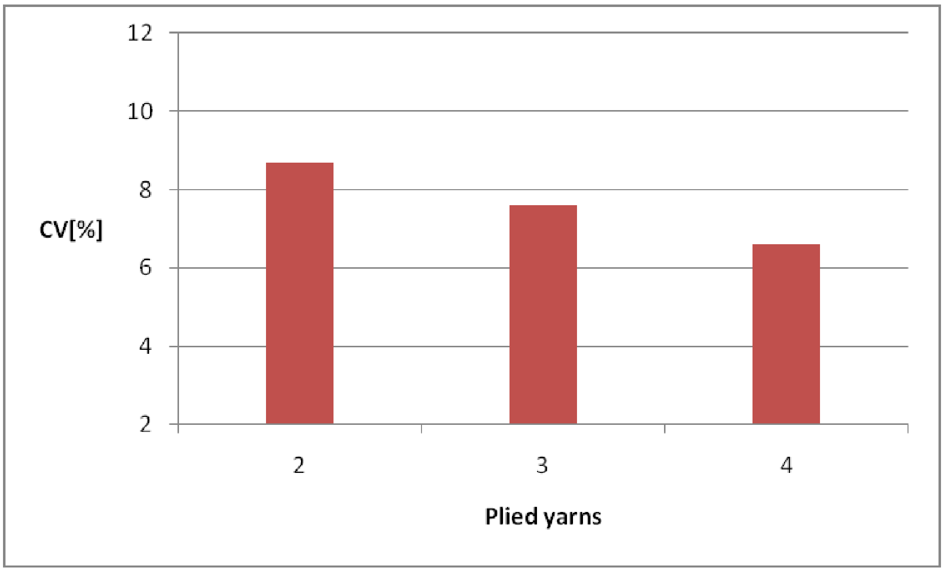

Figure 21: Mass irregularity vs two, three and four ply yarn (50 tex).

From fig 21, It can be seen that the more the number of plying is increasing, mass irregularity of yarns is minimized. Two ply yarns has a high mass irregularity than the four ply yarn. Tenacity also minimize mass irregularity as the four ply yarn has a high value of tenacity than the three and two plied yarns.

6.4. Procedure of measuring elongation and twist

These measurement was done according to the standard CSN 800700. The humidity in the laboratory was 65 % with temperature ranges between (20 – 25)^{o}C. For all the yarns 20 tex, 29.5 tex and 50 tex, a measurement of fifty times was taken for each individual yarns. After the measurement the average value was done with the standard deviation. Confidence interval was calculated according to formula (5a). In the Instron machine the clamping length l_2 = 500 mm and the speed of the lower clamp jaw was 100 mm/ min for 20 tex and 120 mm/m for 29.5 tex and 50 tex.

6.4.1. Influence of ply twist on the elongation

<u>20 tex yarn</u>

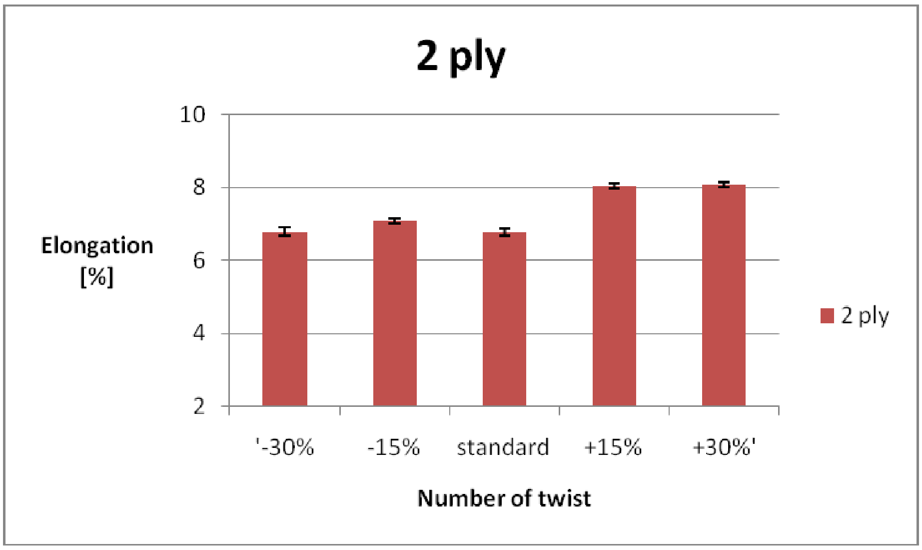

Figure 22: Elongation vs number of twist of yarn for two ply yarn (20tex).

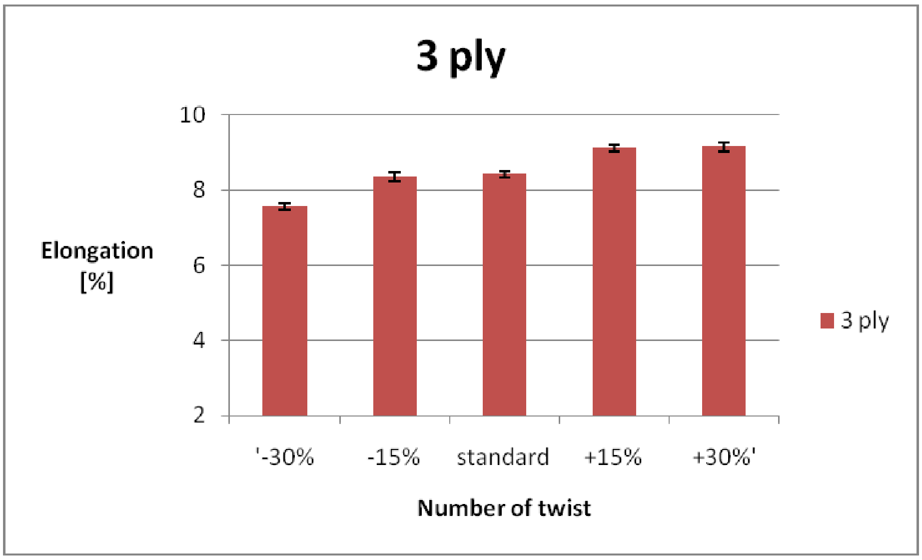

Figure 23: Elongation vs number of twist of yarn for three ply yarn (20 tex).

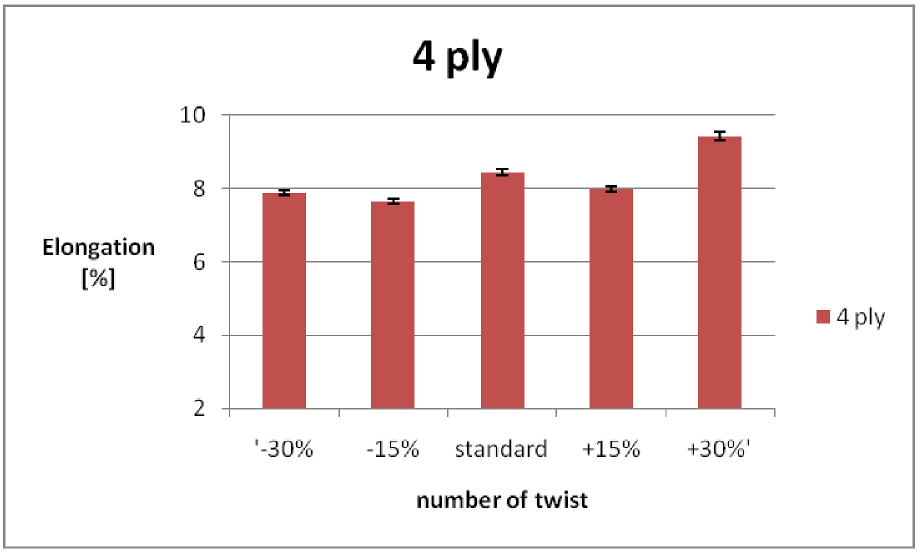

Figure 24: Elongation vs number of twist of yarn for four ply yarn (20tex).

In figure 22, the spinning method used when the yarns are produced as well as setting the twist of yarn has an influence in the results. For these minus fifteen yarn has high number or value of elongation than the standard yarn while the standard yarn has high number of twist compared to minus fifteen percent.The ply twist and change of single yarn twist has main influence. In these graph , standard yarn, fifteen percent yarn and the thirty percent yarn has shown that elongation is dependent on the number of twist. It can be seen that the more the number of ply twist is increased also the number of elongation is increased. According to theory, elongation should increase with increasing number of ply twist. But due to contrary plying, spinning twist is decreasing. Thus, elongation in dependence on number of ply twist can fluctuate.

In figure 23, as the number of twist increases also the value of elongation increases also. Starting from the minus thirty percent yarn to the thirty percent yarn the graph is increasing as the number of twist goes up. These shows that elongation is dependent on the number of ply twist. When the confidence interval overlaps, there is no big difference. The value of elongation of a three ply yarn are high compared to the value of elongation of the two ply yarn.

In figure 24, The four ply yarn graph shows that number of twist has an influence in elongation. When the value of twist is high also the value of elongation increase. For an example looking at the fifteen percent and the thirty percent yarn in four ply yarn, the thirty percent yarn has a higher value than the fifteen percent yarn. But these is not the case in the minus fifteen percent yarn and minus thirty percent yarn as the number of elongation is lower than the minus thirty percent looking at that minus fifteen percent has high number of twist than minus thirty percent yarn. The above results can be influenced by irregularity of twisted yarns also.

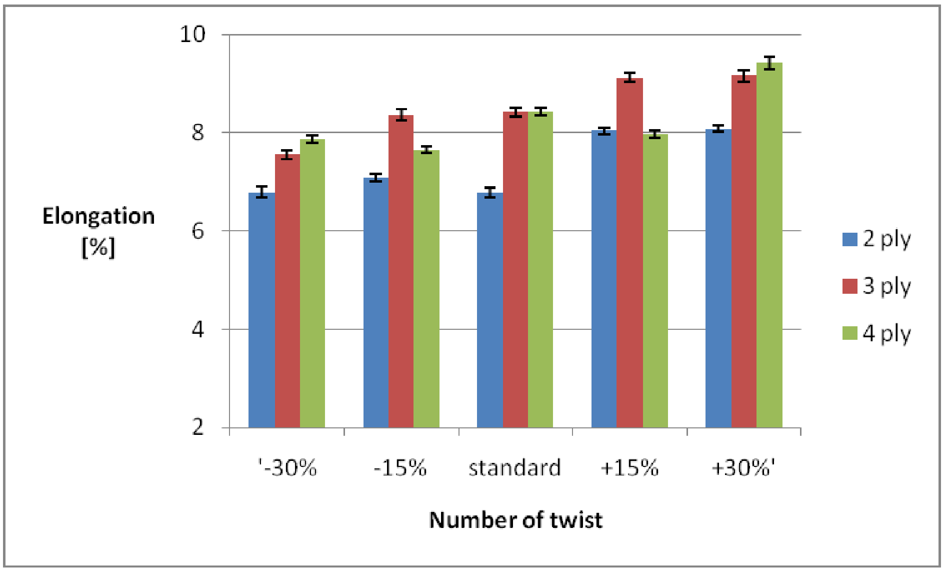

Figure 25: Elongation vs number of twist for two, three and four ply yarn (20 tex).

From the figure it has been seen that number of twist has an influence in the elongation of yarn. Increasing the number of plied yarn for example making it three ply yarn, the number or value of elongation is higher than the two ply yarn. But in my results in some yarn it is not the case, like in the minus fifteen percent of two, three and four ply yarn.The number of single yarn in ply yarn influences elongation, but the other effects can affects this course.

6.4.2. Tenacity as a function of number of ply twist

<u>20 tex yarn</u>

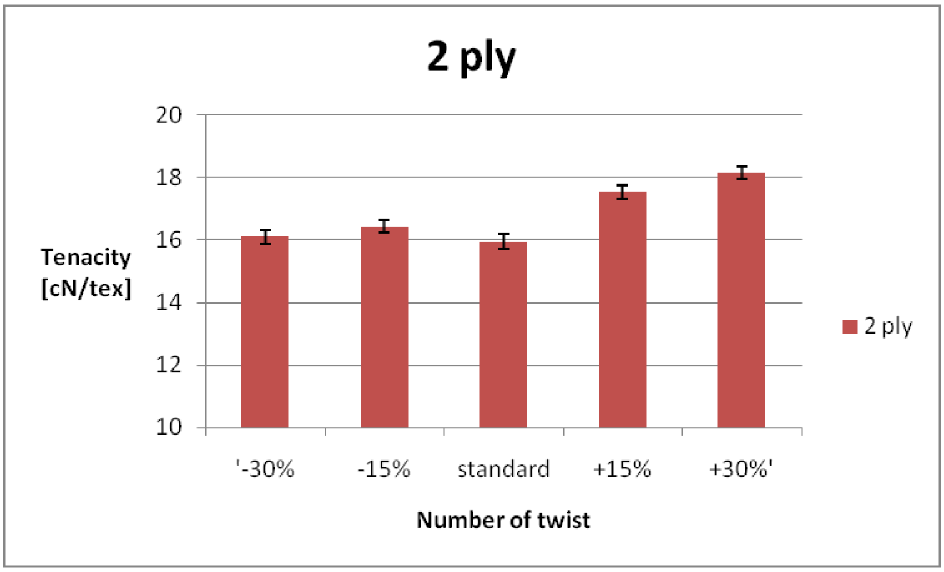

Figure 26: Tenacity vs number of twist for two ply yarn (20 tex).

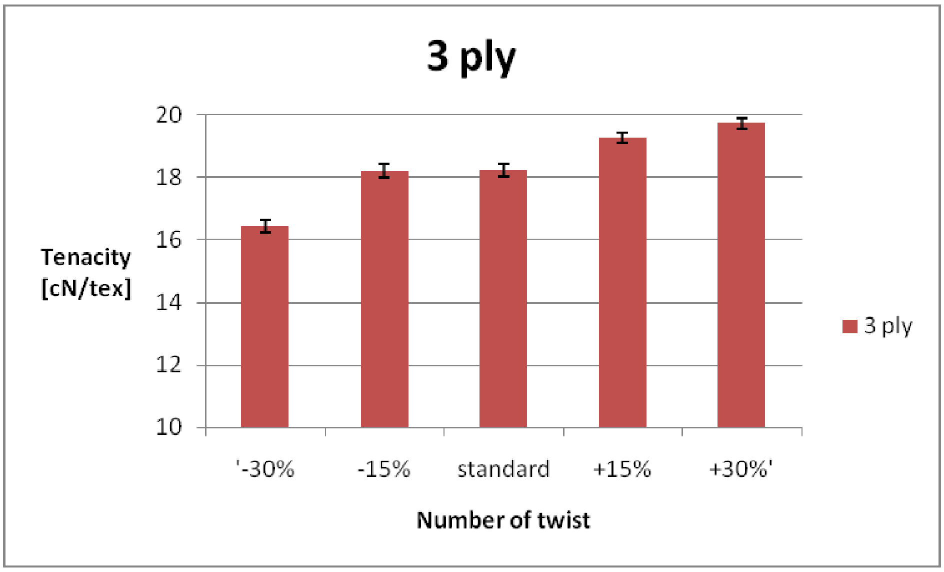

Figure 27: Tenacity vs number of twist of yarn for three ply yarn (20 tex).

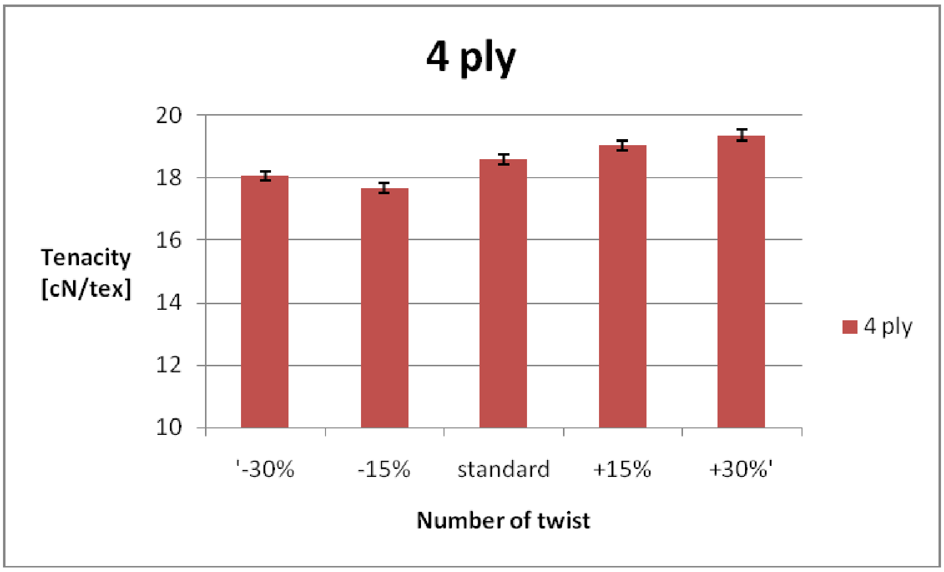

Figure 28: Tenacity vs number of twist of yarn for four ply yarn (20tex).

In the figure 26, The results looks fine, they are supporting that the number of twist has an influence in tenacity. that means tenacity is dependent on the number of twist. It can be seen in the graph that the confidence interval overlaps, which means there is no big difference. The ply twist has a main effect, but other influences take effect – for example the change of the angle β.

In the figure 27, When comparing the value of tenacity of the three ply yarn and the two ply yarn with the same tex, it can be seen that the three ply yarn has a high value of tenacity to the two ply yarn. The results support that as the number of twist increases also the the value of tenacity increase. These is the same from the begginning from the minus thirty percent yarn to the thirty percent yarn.

In the figure 28, the number of twist of yarn has an influence on tenacity. The more you increase the number of twist also the number of tenacity increases. These can be supported by the graph of tenacity vs number of twist in four ply yarn. There is an increase in tenacity from the standard yarn to the thirty percent yarn. But the value of the minus fifteen percent yarn is lower than the minus thirty percent yarn, the above results can be influenced by irregularity of twisted yarns also.

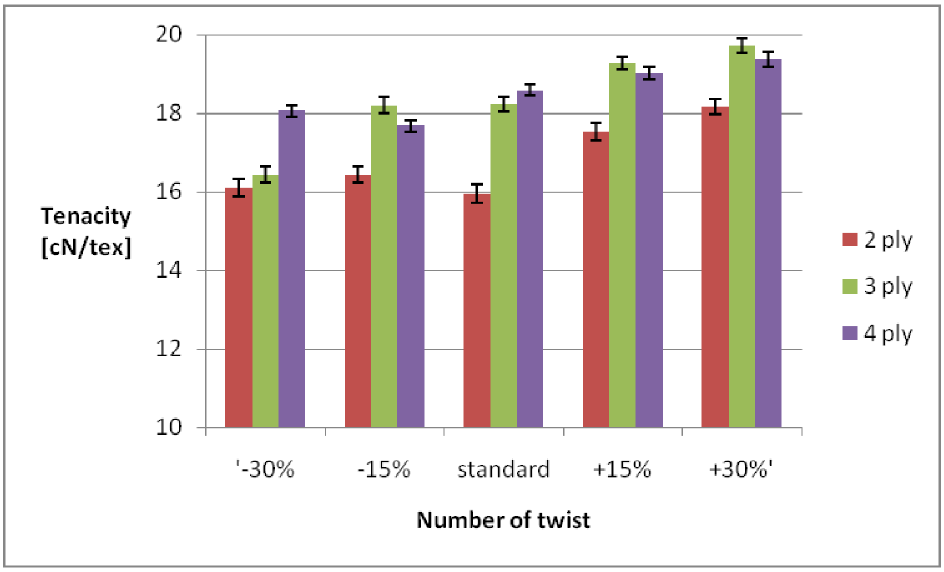

Figure 29: Tenacity vs number of twist of yarn for two, three and four ply (20 tex).

It can be seen that there more you increase the number of plied yarn also the number of tenacity increases. These shows that increases the number of plied yarn has an influence in tenacity. If the minus thirty yarn can be considered for two,three and four plied yarns, it can be seen that the four ply yarn has high tenacity than the three and two ply yarn. But in some situation where there is a little different, the confidence intervals are closer to each other. Example of these is the fifteen percent yarn.

6.4.3. Influence of ply twist on the elongation

<u>29.5 tex yarn</u>

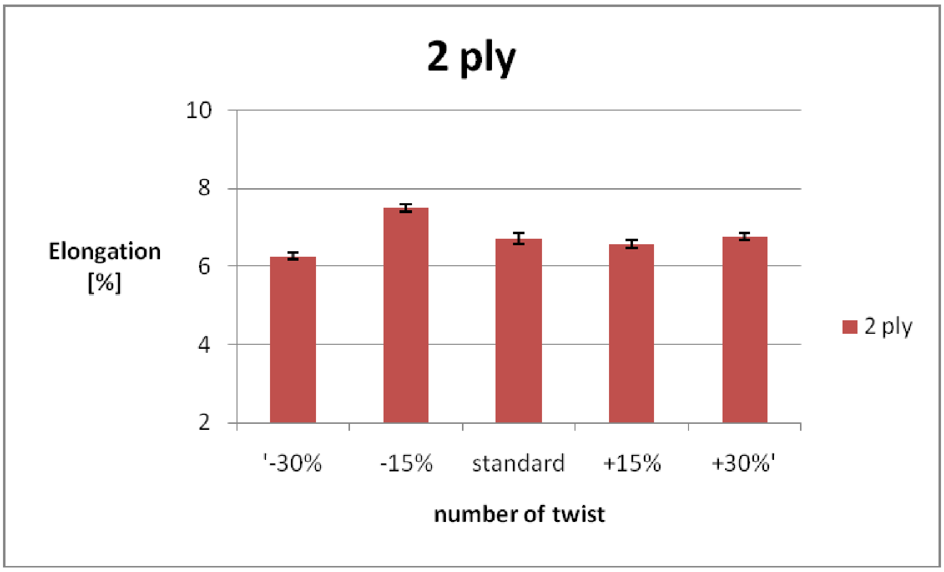

Figure 30: Elongation vs number of twist for two ply yarn (29.5 tex).

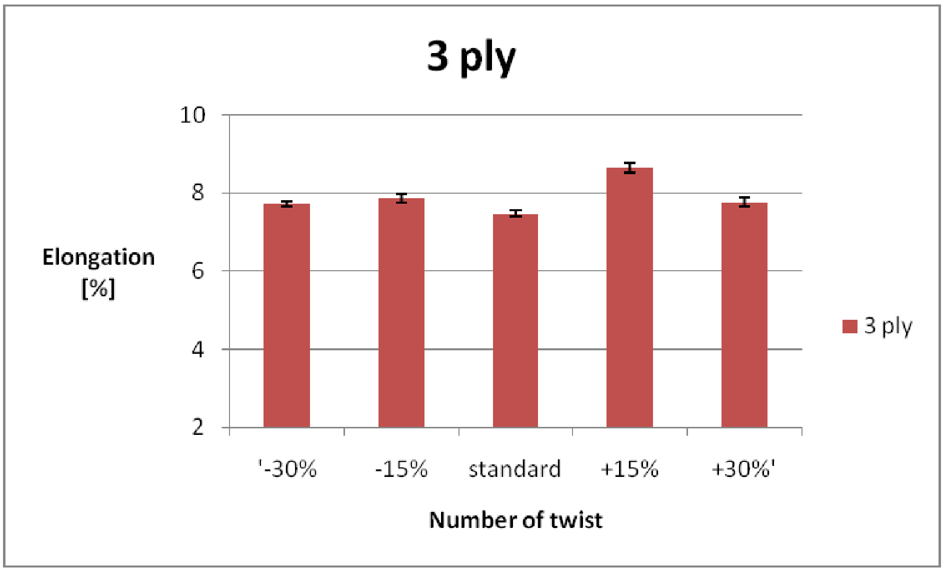

Figure 31: Elongation vs number of twist for three ply yarn (29.5 tex).

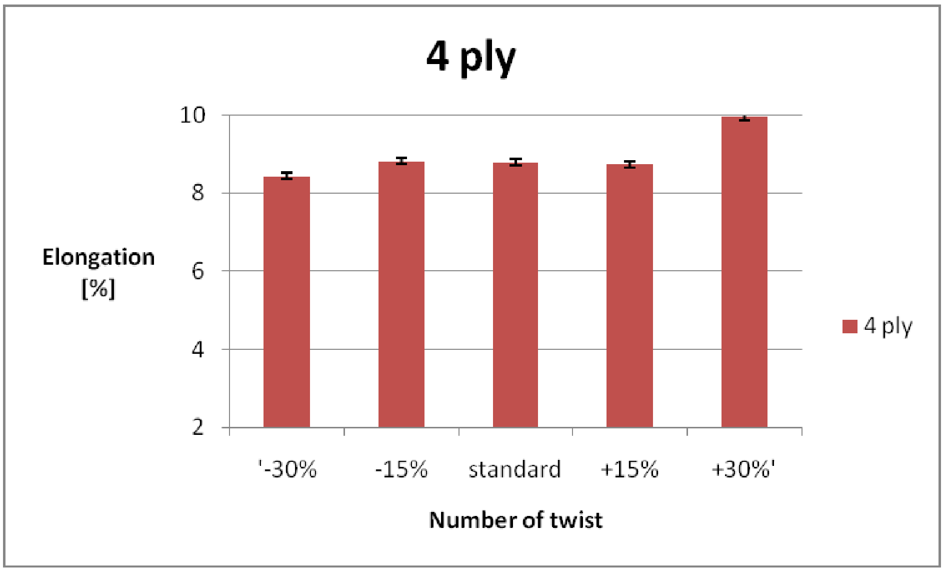

Figure 32: Elongation vs number of twist for four ply yarn (29.5 tex).

In the figure 30, Elongation is dependent on the number of twist, the more the number of twist is increased also the value of elongation goes up. But in these graph it is not the case as the minus fifteen percent yarn has a higher value of elongation than all other yarns. The standard yarn, fifteen percent yarn and the thity percent yarn has a high number of twist compared to the minus fifteen percent yarn but their values of elongation is lower comparing to minus fifteen percent yarn. These can be caused by the structure of the yarn, the properties of the minus fifteen percent yarn. Human error also has an influence in yarn manufacturing. Twist multiple and linear density are important parameters to determined the character of a twisted yarn made from a given fibres.

In the figure 31, The thity percent yarn has a lower value of elongation than the fifteen percent yarn even thou its number of twist is high than the fifteen percent yarn. These can be seen also in the standard yarn that its value of elongation is lower than the minus thirty percent yarn and minus fifteen yarn. But the graph starts very well in the beginning of the two yarns, minus thirty percent yarn has a lower value of elongation than the minus fifteen percent yarn. Which is true as the number of twist of minus fifteen percent yarn is higher than the twist of minus thirty percent yarn. These support or give evidence that elongation is dependent on the number of twist.

In the figure 32, It is interesting to find that the thirty percent yarn has a high value of elongation compared to the other yarns. These is true and it was expected as the number of twist of the thirty percent yarn is higher compared to the minus thirty percent yarn, minus fifteen percent yarn, standard and thirty percent yarn. Confidence interval for these graph overlaps which means there is no big difference.

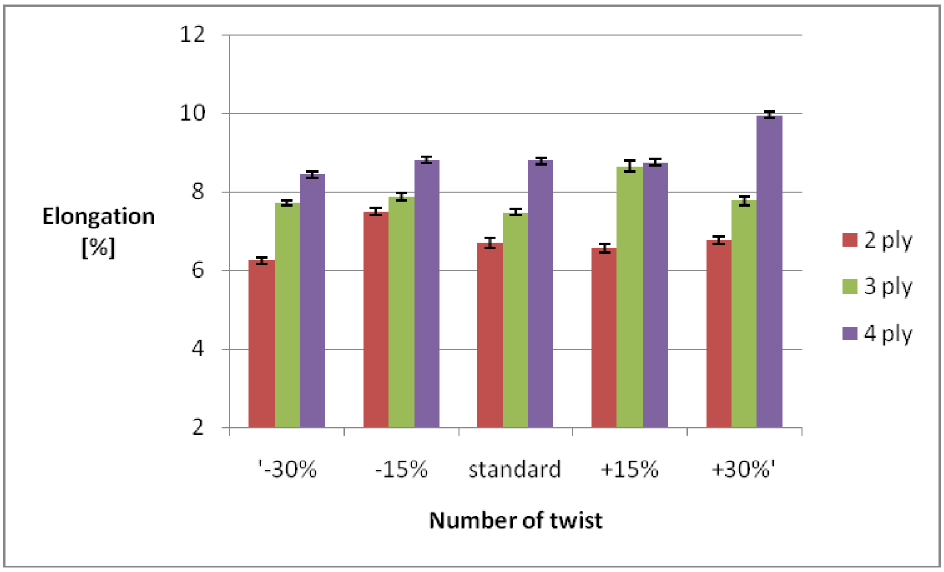

Figure 33: Elongation vs number of twist of yarn for two, three and four ply yarn (29.5).

It can be seen that number of twist has an influence on elongation, there more the number of plied yarn increased means that also the number of elongation will be high. Four ply yarn has a high number of elongation than the three ply yarn and the two ply yarn. The confidence interval overlaps, which means there is no such big difference. Example can be seen in minus thirty percent yarn and the minus fifteen yarn.

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6.4.4. Tenacity as a function of number of ply twist

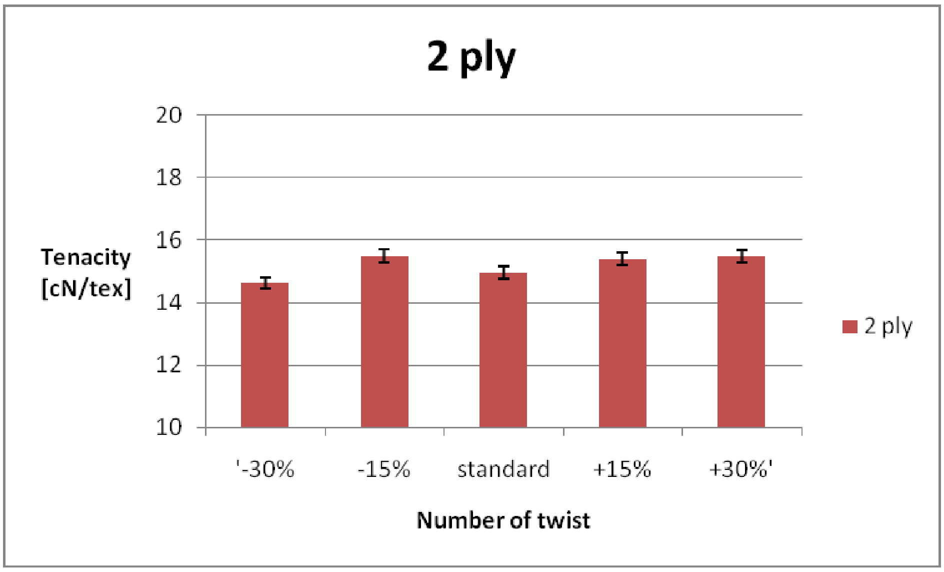

Figure 34: Tenacity vs number of twist for two ply yarn (29.5 tex).

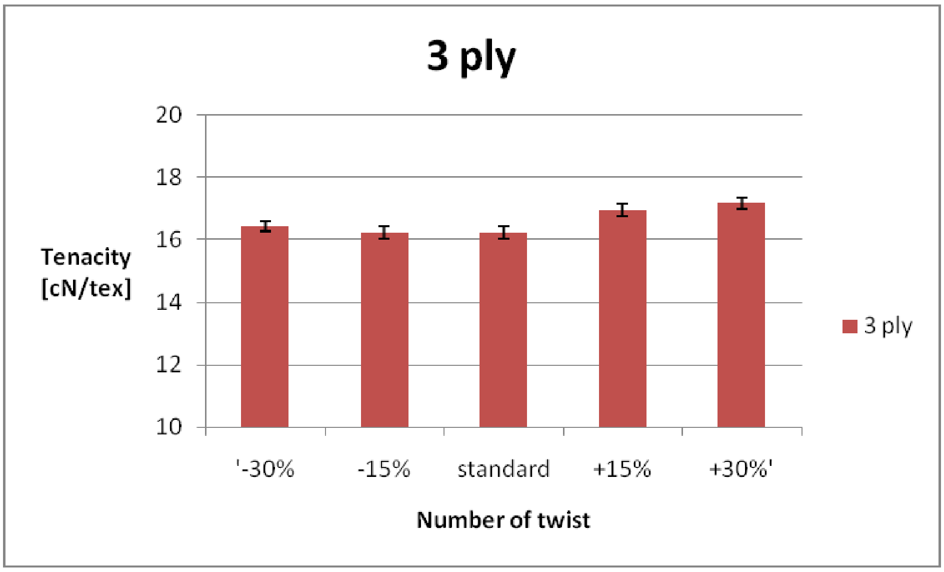

Figure 35: Tenacity vs number of twist for three ply yarn (29.5 tex).

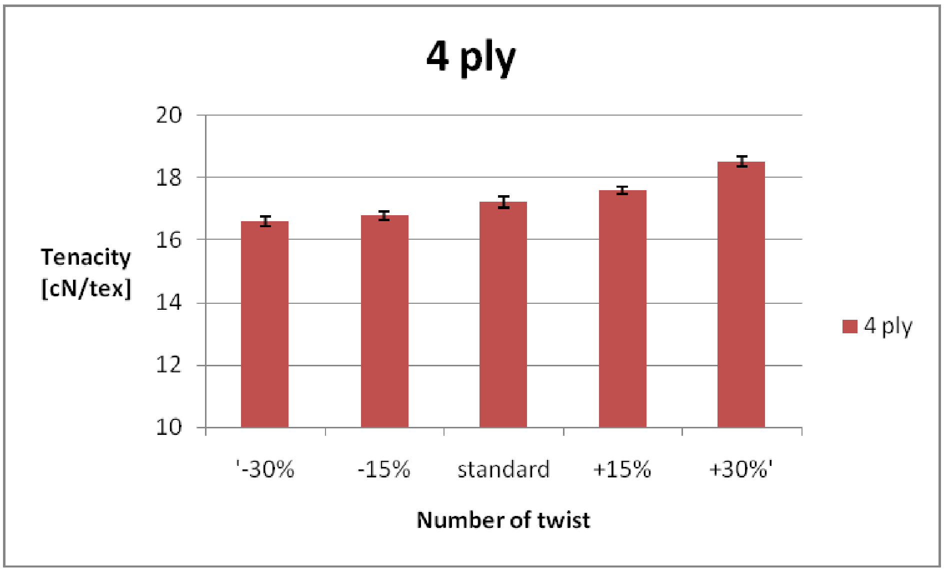

Figure 36: Tenacity vs number of twist for four ply yarn (29.5 tex).

In figure 34, in the beginning from minus thirty percent yarn to the minus fifteen percent yarn it can be seen that when the number of twist is incresing also the number or value pf tenacity increases. The standard yarn instead of icreasing the value of tenacity as its number of twist is higher than minus fifteen percent, value of tenacity goes down or lower. These results can be caused by the fiber properties and mass irregularity on the yarns. The standard yarn, fifteen percent yarn and thirty percent yarn is fine as tenacity is increasing with the number of twist.

In figure 35, the first three yarns shows that when the number of twist was increasing, the value of tenacity was a little bit not increasing. Their values of tenacity are closer to each other, confidence intervals overlaps. But from the standard yarn to thirty percent yarn it can be seen that when the number of twist is increasing also the value of tenacity is increasing. These results can be affected by the strength of the yarn, technically spinning method used to manufacture the yarn has an influence with the results with the twist of the yarn.

In figure 36, as is known that the number of twist has an influence on tenacity, the graph of four ply yarn shows it all that the more the number of twist is increased, the number of tenacity increase also. It can be seen from minus thirty percent up to the thirty percent yarn. There is not that much differences when considering their confidence intervals as they overlaps.

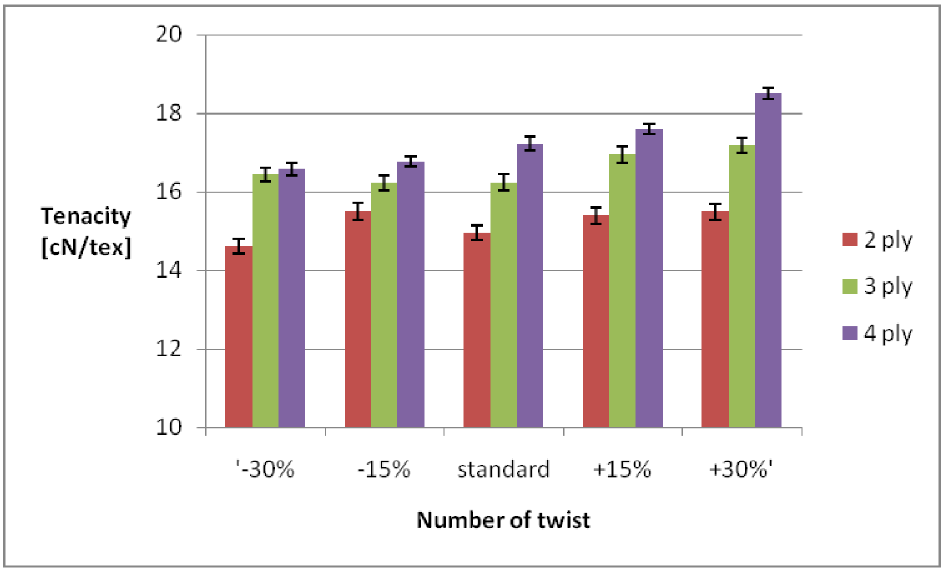

Figure 37: Tenacity vs number of twist of yarn for two, three and four ply yarn (29.5 tex).

Increasing the number of plying for example four ply yarn it needs more value of tenacity. These is shown in the graph that four ply yarn has higher value of tenacity than the three ply and two ply. But considering the two ply yarn only it can be seen that the value of tenacity in the biggining was increasing when coming to standard yarn it goest down. Whether the fibres used where short or longer has an influence on tenacity. These can be also supported by the moisture or temperature where the material was placed.

6.4.5. Influence of ply twist on the elongation

50 tex yarn

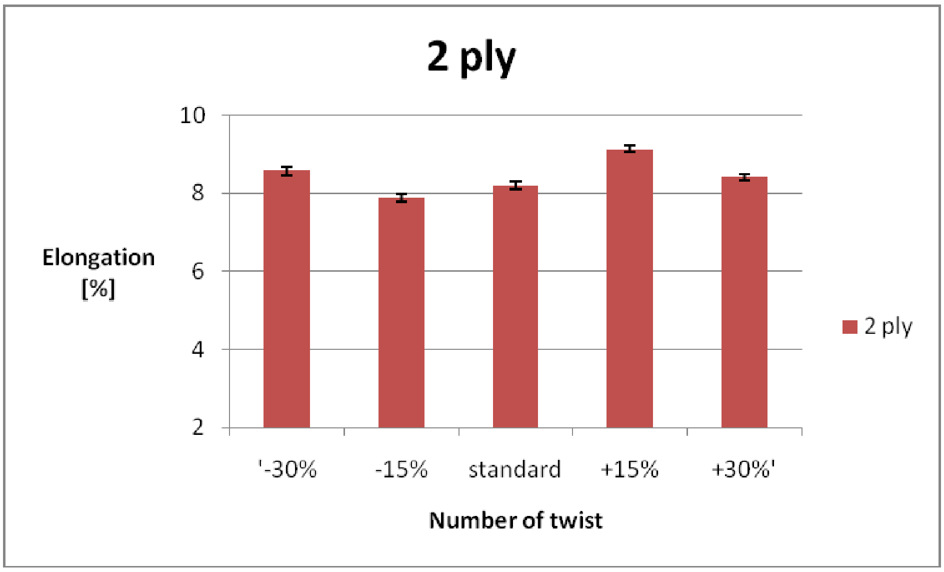

Figure 38: Elongation vs number of twist for two ply yarn (50 tex).

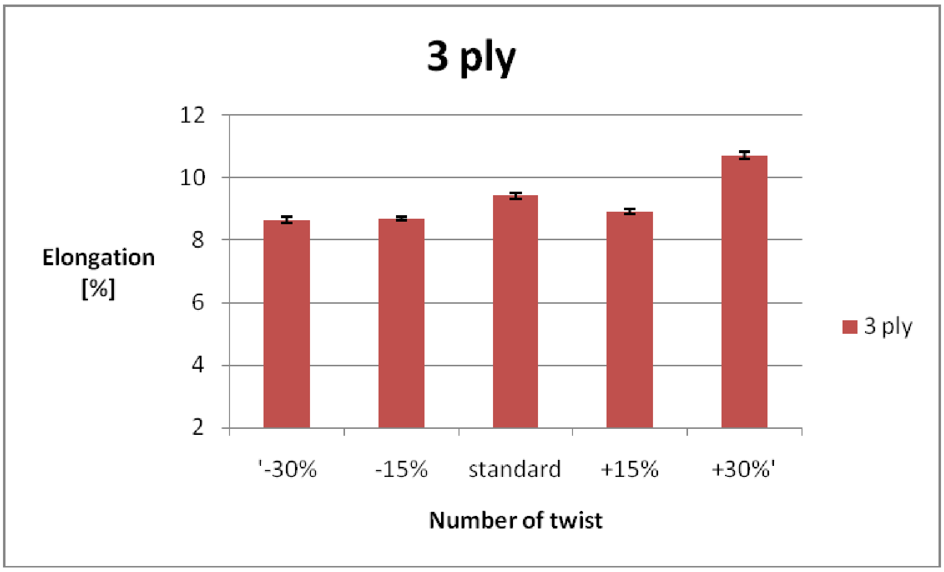

Figure 39: Elongation vs number of twist for three ply yarn (50 tex).

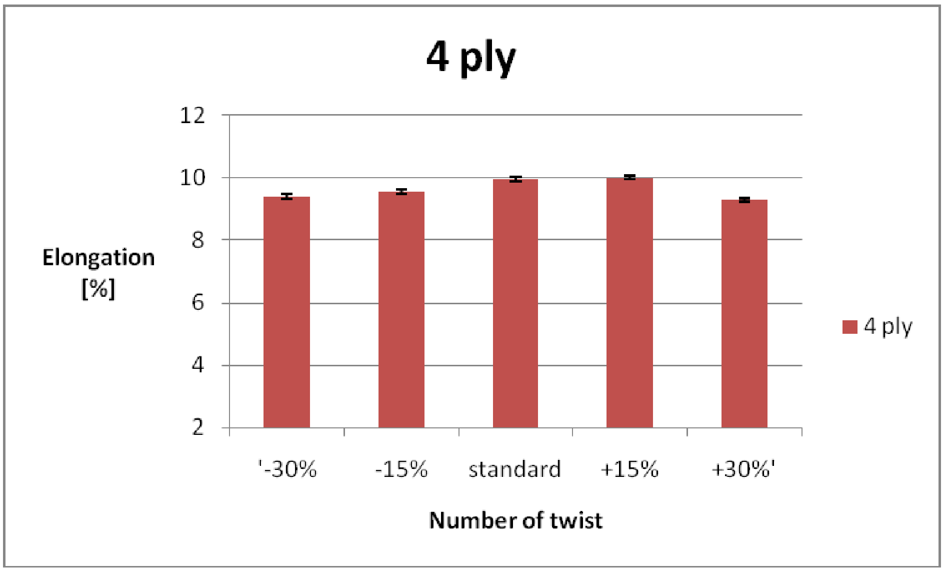

Figure 40: Elongation vs number of twist for four ply yarn (50 tex).

In figure 38, in the graph above, minus thirty percent yarn has higher number of elongation than the minus fifteen and standard yarn. Also the fifteen percent has higher value of elongation even thou its twist value is lower than the tirty percent yarn. The results can be because of mass irregularity of twisted yarns and human error during manufacturing. Also the machine used to analyze the results has an influence in the results.

In figure 39, the confidence interval for first four yarns minus thirty percent, minus fifteen percent yarn, standard yarn and the fifteen percent yarn overlaps, which means there is no big difference. The difference is not that much big except for the last yarn which is the thirty percent yarn. In the beginning the number of elongation for both yarns is increasing but when coming to the fifteen percent yarn it comes down. These can be because of the ply twist has a main effect, but other influences take effect – for example the change of the angle β.

In figure 40, as elongation is dependent on the number of twist, it can be seen in the last yarn that there is something wrong as the value of the thirty percent yarn was suppose to be higher than the others as it has a high number of twist. Mass irregularity during twisting has an influence with the results. But the results of the other yarns is fine as the value of elongation is increasing with the number of twist.

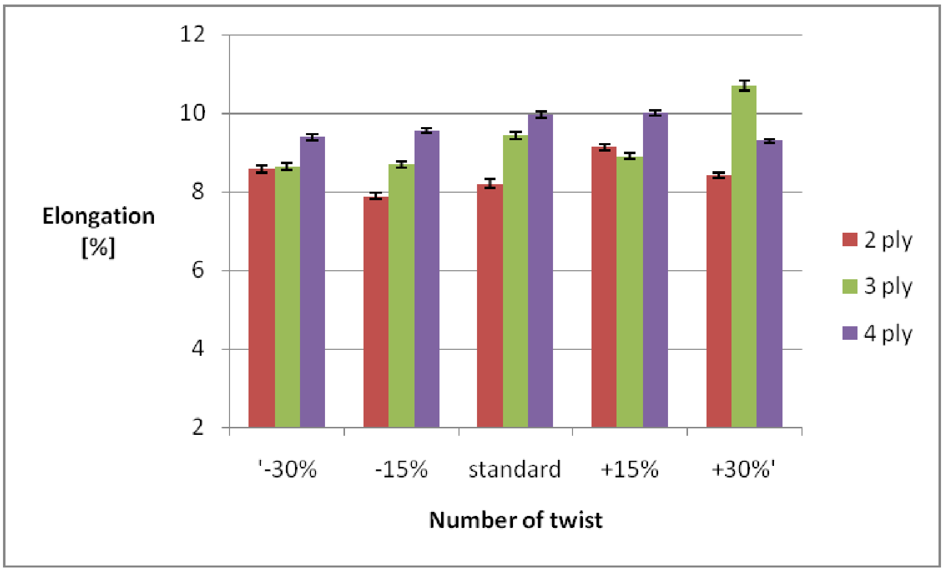

Figure 41: Elongation vs number of twist of yarn for two, three and four ply yarn (50 tex).

The first three yarns minus 30 percent, minus fifteen percent and the standard yarn are supporting that the more the number of plied yarn increased also the value of elongation goes up. But these is not the same in the fifteen percent and the thirty percent. The value of elongation for a four ply yarn is smaller than the value of elongation of three ply yarn. These can be because of fibres used or how the yarns have been affected by temperature or moisture in the place where they have been placed. The ply twist has an effect in the results.

6.4.6. Tenacity as a function of number of ply twist

50 tex yarn

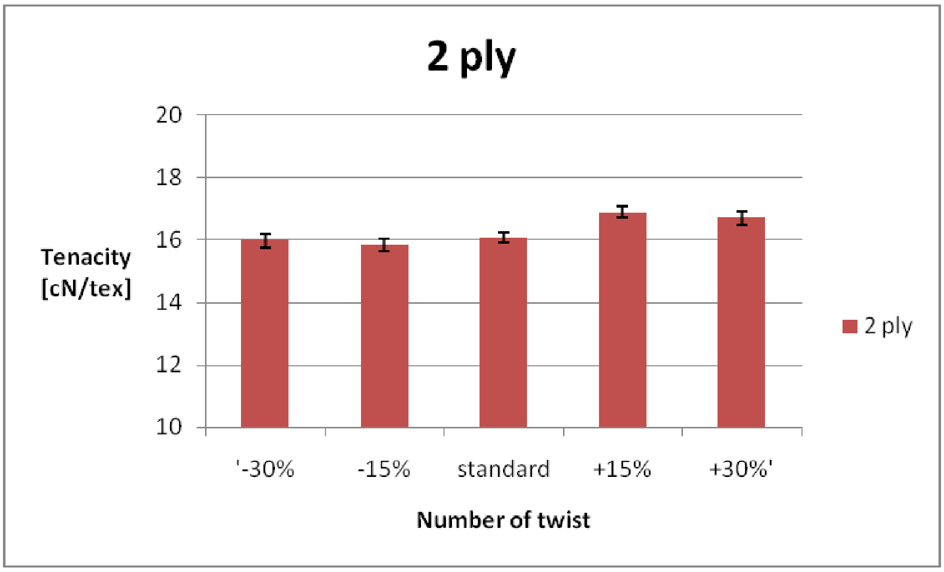

Figure 42: Tenacity vs number of twist for two ply yarn (50 tex).

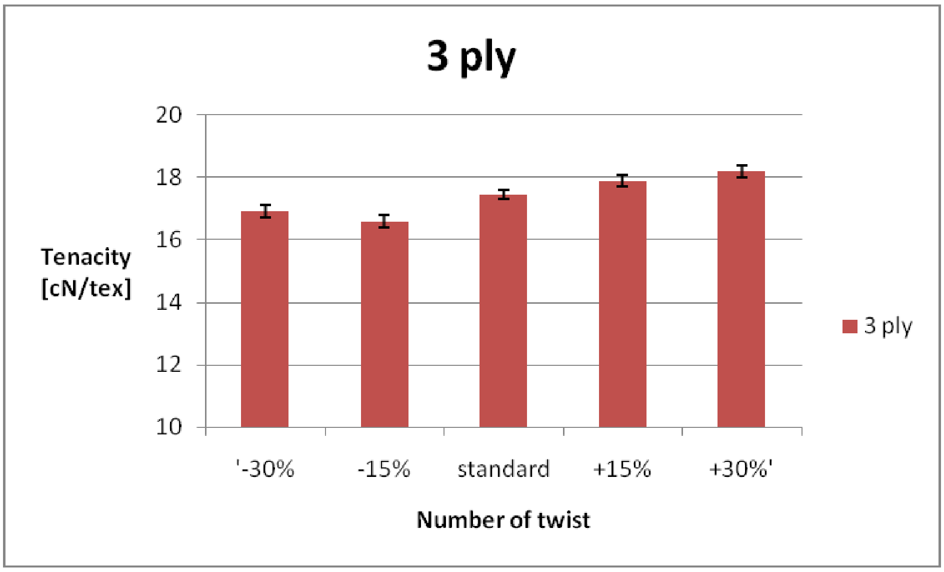

Figure 43: Tenacity vs number of twist for three ply yarn (50 tex).

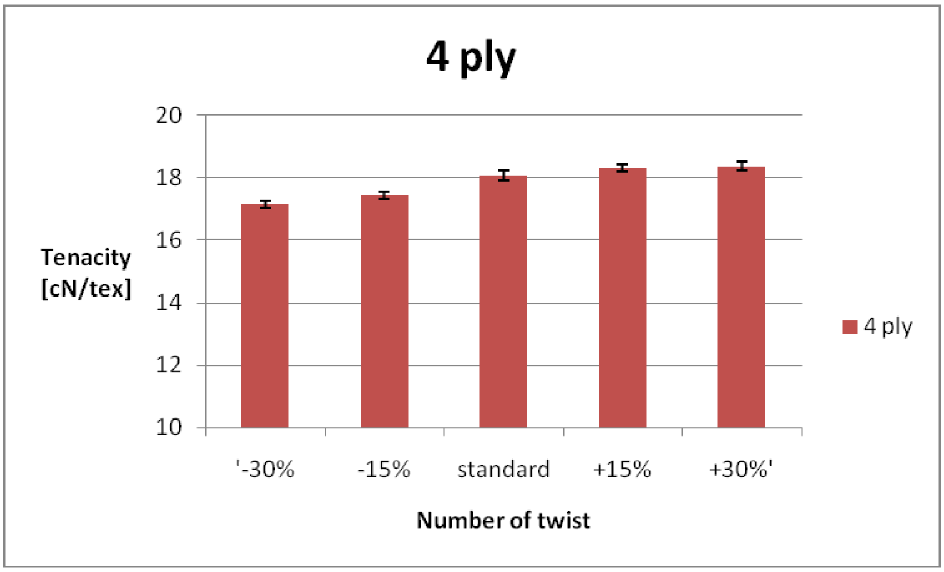

Figure 44: Tenacity vs number of twist for four ply yarn (50 tex).

In the figure 42, tenacity is dependent on the number of twist, the more the number of twist goes up also the value of tenacity has to go up. But the minus fifteen percent yarn has a lower value of tenacity, but its number of twist is higher than the minus thirty percent yarn. The last yarn which is thirty percent yarn has a lower value of tenacity than the fifteen percent yarn, but it can be seen that the confidence interval between the two yarns is minimal. Mass irregularity during twisting has an influence in the results.

In the figure 43, These graph is supporting that the more the number of twist goes up, the value of tenacity goes up also. These is not in the case of minus fifteen percent yarn as it has a lower value of tenacity comparing to the other yarns. From the experiment the value of number of twist of the minus fifteen percent it is greater than the minus thirty percent yarn. Which means it was suppose to be high than the minus thirty percent if the value of tenacity where to be considered.

In the figure 44, number of twist has an influence in tenacity. when the number of twist increases also tenacity goes up. From the minus thirty yarn to the thirty yarn, the value of tenacity increases. But also there is a smaller difference in confidence interval, it overlaps. The angle β has an influence in the results.

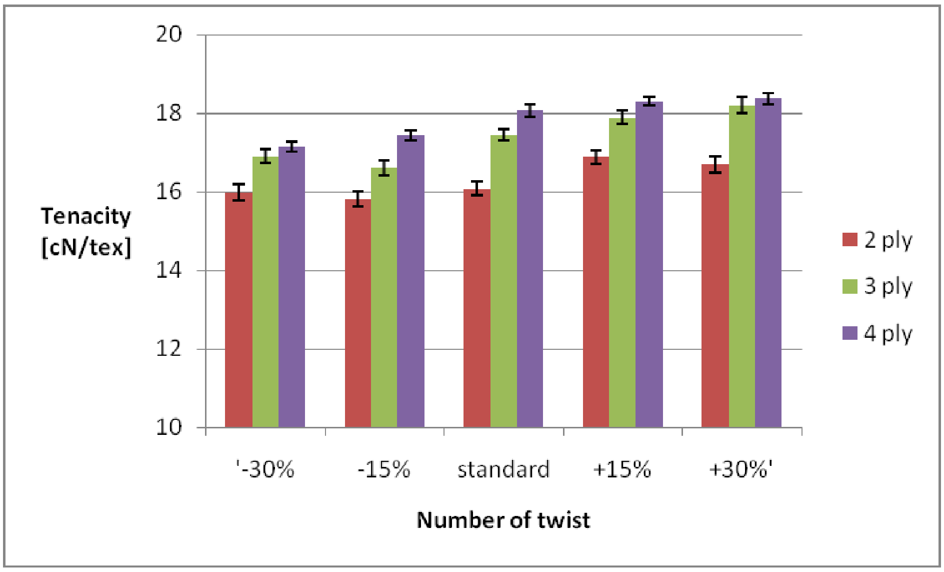

Figure 45: Tenacity vs number of twist of yarn for two, three and four ply yarn (50 tex).

These results shows that there more the number of plied yarn also the number of tenacity increase. The value of tenacity for four ply yarn is higher than the three ply yarn and the two ply yarn. It can be concluded that increasing the number of plying has an influence in the number of tenacity. four ply yarn is stronger than the three ply yarn and the two ply yarn. These can be supported by the results in the graph from above.

7. Conclusion

From the results it has been shown that mass irregularity is independent in the number of twist. An example is the fifteen percent yarn has lower value of mass irregularity compared to the standard and the thirty percent yarn. It has been found that by plying the yarn and increasing the number of tex minimize mass irregularity. Doubling also has an influence in the mass irregularity of yarn, it is the main effect of mass irregularity as high doubling makes irregularity smaller or lower. A four ply yarn has lower value of mass irregularity than the three and two ply yarn. Human error also is another problem in mass irregularity. With increasing number of ply twist the elongation should increase.The ply twist and change of single yarn twist has main influence on results.Results can be influenced by irregularity of twisted yarns too.The number of single yarn in ply yarn influences elongation, but the other effects can affects this course.

Tenacity is dependent on the number of twist, the more the number of twist increases also the number of tenacity goes high. When the number of plying increases also the value of tenacity increases. Example of these is in the graph of tenacity vs number of twist. Four ply yarn has higher value of tenacity than the three ply yarn and the two ply yarn. But also the type of fibres used has an influence, these include if the fibres where short or longer. With moisture and temperature also affecting the results. Tenacity is influence by structure of yarn and mechanical properties of fibres. Yarn structure is influence by radial disposition of fibres along the yarn length called migration. Packing density of fibres in the yarn cross section has an influence on tenacity. All these are affected by fibre properties, yarn factors and spinning process and the dynamics preparation. The technology applied and machine setting has an influence on yarn strength. Good technology has to be taken into consideration or selected in order to achieve good properties and production economy. Number of single yarns in the ply yarn has strong influence on ply yarn irregularity. Number of ply twist has influence on elongation and tenacity. Thus resultant dependence are not absolutely explicit (unique), but the influence of ply twist on increasing of tenacity as well as elongation predominates. The ply twist has a main effect on yarn tenacity , but other influences take effect too– for example the change of the angle β. During final decision, properties of final yarn play a role together with economical questions as well as area of utilization of this yarns.

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9. Appendix

9.1 Confidence interval from the Uster tester results.

Table 4: Confidence interval for 20 tex (mass irregularity).

Twist of two ply yarn [m^{-1}]	Minimum confidence interval CV[%]	Maximum confidence interval CV[%]	Twist of three ply yarn [m^{-1}]	Minimum confidence interval CV[%]	Maximum confidence interval CV[%]	Twist of four ply yarn [m^{-1}]	Minimum confidence interval CV[%]	Maximum confidence interval CV[%]
490	9.12	9.32	400	7.60	7.78	250	6.80	6.96
590	9.38	9.60	480	7.93	8.11	310	6.91	7.07
690	9.45	9.67	560	7.59	7.77	370	6.93	7.09
790	8.81	8.99	640	7.32	7.48	430	6.95	7.11
890	9.18	9.38	720	7.35	7.51	490	5.77	5.91

Table 5: Confidence interval for 29.5 tex (mass irregularity).

Twist of two ply yarn [m^{-1}]	Minimum confidence interval CV[%]	Maximum confidence interval CV[%]	Twist of three ply yarn [m^{-1}]	Minimum confidence interval CV[%]	Maximum confidence interval CV[%]	Twist of four ply yarn [m^{-1}]	Minimum confidence interval CV[%]	Maximum confidence interval CV[%]
360	10.33	10.57	260	8.77	8.97	210	7.67	7.85
440	9.91	10.13	320	8.38	8.56	250	7.68	7.86
520	10.18	10.42	380	8.73	8.93	290	7.73	7.91
600	10.04	10.26	440	8.19	8.37	330	7.78	7.96
680	9.89	10.11	500	8.52	8.72	370	7.18	7.34

Table 6: Confidence interval for 50 tex (mass irregularity).

Twist of two ply yarn [m^{-1}]	Minimum confidence interval CV[%]	Maximum confidence interval CV[%]	Twist of three ply yarn [m^{-1}]	Minimum confidence interval CV[%]	Maximum confidence interval CV[%]	Twist of four ply yarn [m^{-1}]	Minimum confidence interval CV[%]	Maximum confidence interval CV[%]
265	8.4	8.58	140	7.48	7.64	170	6.56	6.70
320	8.91	9.11	220	7.55	7.73	200	6.60	6.74
375	8.87	9.07	300	7.53	7.71	230	6.56	6.70
430	8.79	8.99	380	7.65	7.83	260	6.38	6.52
485	7.94	8.12	460	7.37	7.53	290	6.45	6.59

9.2 Confidence interval from the Instron machine results.

Table 7: Confidence interval for 20 tex (Elongation).

Two ply

Twist of two ply yarn [m^{-1}]	Average value of elongation [%]	Minimum confidence interval [%]	Maximum confidence interval [%]	Standard deviation
490	6.79	6.67	6.90	1.97
590	7.08	6.99	7.16	1.49
690	6.78	6.14	6.88	1.87
790	8.04	7.96	8.11	1.28
890	8.08	8.01	8.14	1.23

Table 8: Confidence interval for 20 tex (Elongation).

Three ply

Twist of three ply yarn [m^{-1}]	Average value of elongation [%]	Minimum confidence interval [%]	Maximum confidence interval [%]	Standard deviation
400	7.56	7.47	7.64	1.57
480	8.36	8.24	8.47	1.98
560	8.42	8.33	8.51	1.60
640	9.12	9.03	9.20	1.54
720	9.6	9.48	9.71	2.04

Table 9: Confidence interval for 20 tex (Elongation).

Four ply

Twist of four ply yarn [m^{-1}]	Average value of elongation [%]	Minimum confidence interval [%]	Maximum confidence interval [%]	Standard deviation
250	7.87	7.80	7.93	1.15
310	7.65	7.59	7.71	1.08
370	8.44	8.36	8.51	1.36
430	7.98	7.90	8.05	1.34
490	9.42	9.30	9.53	2.05

Table 10: Confidence interval for 20 tex (Tenacity).

Two ply

Twist of two ply yarn [m^{-1}]	Average value of tenacity [cN/tex]	Minimum confidence interval [cN/tex]	Maximum confidence interval [cN/tex]	Standard deviation
490	16.10	15.88	16.32	0.80
590	16.43	16.22	16.64	0.75
690	15.95	15.71	16.19	0.87
790	17.54	17.32	17.76	0.80
890	18.15	17.96	18.34	0.68

Table 11: Confidence interval for 20 tex (Tenacity).

Three ply

Twist of three ply yarn [m^{-1}]	Average value of tenacity [cN/tex]	Minimum confidence interval [cN/tex]	Maximum confidence interval [cN/tex]	Standard deviation
400	16.43	16.23	16.63	0.71
480	18.21	18	18.42	0.75
560	18.23	18.04	18.42	0.67
640	19.27	19.12	19.42	0.55
720	19.73	19.54	19.92	0.67

Table 12: Confidence interval for 20 tex (Tenacity).

Four ply

Twist of four ply yarn [m^{-1}]	Average value of tenacity [cN/tex]	Minimum confidence interval [cN/tex]	Maximum confidence interval [cN/tex]	Standard deviation
250	18.06	17.91	18.21	0.54
310	17.68	17.53	17.83	0.55
370	18.59	18.44	18.74	0.55
430	19.02	18.86	19.18	0.57
490	19.39	19.2	19.58	0.68

Table 13: Confidence interval for 29.5 tex (Elongation).

Two ply

Twist of two ply yarn [m^{-1}]	Average value of elongation [%]	Minimum confidence interval [%]	Maximum confidence interval [%]	Standard deviation
360	6.25	6.17	6.33	1.53
440	7.49	7.39	7.59	1.84
520	6.71	6.58	6.84	2.43
600	6.57	6.46	6.68	1.99
680	6.76	6.66	6.86	1.88

Table 14: Confidence interval for 29.5 tex (Elongation).

Three ply

Twist of three ply yarn [m^{-1}]	Average value of elongation [%]	Minimum confidence interval [%]	Maximum confidence interval [%]	Standard deviation
260	7.72	7.65	7.79	1.25
320	7.87	7.77	7.97	1.81
380	7.48	7.4	7.56	1.51
440	8.65	8.51	8.79	2.51
500	7.77	7.66	7.88	1.98

Table 15: Confidence interval for 29.5 tex (Elongation).

Four ply

Twist of four ply yarn [m^{-1}]	Average value of elongation [%]	Minimum confidence interval [%]	Maximum confidence interval [%]	Standard deviation
210	8.44	8.36	8.52	1.45
250	8.81	8.73	8.89	1.46
290	8.79	8.71	8.87	1.50
330	8.74	8.66	8.82	1.50
370	9.95	9.87	10.03	1.41

Table 16: Confidence interval for 29.5 tex (Tenacity).

Two ply

Twist of two ply yarn [m^{-1}]	Average value of tenacity [cN/tex]	Minimum confidence interval [cN/tex]	Maximum confidence interval [cN/tex]	Standard deviation
360	14.62	14.43	14.81	0.68
440	15.49	15.27	15.71	0.77
520	14.96	14.77	15.15	0.69
600	15.39	15.19	15.59	0.70
680	15.49	15.29	15.69	0.73

Table 17: Confidence interval for 29.5 tex (Tenacity).

Three ply

Twist of three ply yarn [m^{-1}]	Average value of tenacity [cN/tex]	Minimum confidence interval [cN/tex]	Maximum confidence interval [cN/tex]	Standard deviation
260	16.44	16.27	16.61	0.62
320	16.23	16.03	16.43	0.70
380	16.24	16.04	16.44	0.70
440	16.95	16.74	17.16	0.75
500	17.18	16.99	17.37	0.68

Table 18: Confidence interval for 29.5 tex (Tenacity).

Four ply

Twist of four ply yarn [m^{-1}]	Average value of tenacity [cN/tex]	Minimum confidence interval [cN/tex]	Maximum confidence interval [cN/tex]	Standard deviation
210	16.59	16.43	16.75	0.58
250	16.78	16.65	16.91	0.46
290	17.22	17.05	17.39	0.61
330	17.60	17.47	17.73	0.48
370	18.50	18.35	18.65	0.53

Table 19: Confidence interval for 50 tex (Elongation).

Two ply

Twist of two ply yarn [m^{-1}]	Average value of elongation [%]	Minimum confidence interval [%]	Maximum confidence interval [%]	Standard deviation
265	8.57	8.47	8.67	1.89
320	7.89	7.8	7.98	1.63
375	8.20	8.09	8.31	1.99
430	9.14	9.06	9.21	1.38
485	8.42	8.34	8.49	1.33

Table 20: Confidence interval for 50 tex (Elongation).

Three ply

Twist of three ply yarn [m^{-1}]	Average value of elongation [%]	Minimum confidence interval [%]	Maximum confidence interval [%]	Standard deviation
140	8.64	8.54	8.73	1.69
220	8.69	8.62	8.76	1.25
300	9.43	9.33	9.53	1.83
380	8.90	8.82	8.98	1.53
460	10.70	10.58	10.82	2.19

Table 21: Confidence interval for 50 tex (Elongation).

Four ply

Twist of four ply yarn [m^{-1}]	Average value of elongation [%]	Minimum confidence interval [%]	Maximum confidence interval [%]	Standard deviation
170	9.40	9.32	9.48	1.44
200	9.56	9.49	9.63	1.26
230	9.97	9.89	10.05	1.47
260	10.01	9.95	10.07	1.19
290	9.30	9.25	9.35	1.04

Table 22: Confidence interval for 50 tex (Tenacity).

Two ply

Twist of two ply yarn [m^{-1}]	Average value of tenacity [cN/tex]	Minimum confidence interval [cN/tex]	Maximum confidence interval [cN/tex]	Standard deviation
265	15.98	15.76	16.19	0.77
320	15.83	15.64	16.02	0.66
375	16.08	15.90	16.25	0.61
430	16.88	16.7	17.06	0.65
485	16.70	16.49	16.91	0.75

Table 23: Confidence interval for 50 tex (Tenacity).

Three ply

Twist of three ply yarn [m^{-1}]	Average value of tenacity [cN/tex]	Minimum confidence interval [cN/tex]	Maximum confidence interval [cN/tex]	Standard deviation
140	16.91	16.72	17.1	0.68
220	16.61	16.41	16.81	0.70
300	17.44	17.3	17.58	0.49
380	17.89	17.71	18.07	0.63
460	18.20	17.99	18.41	0.77

Table 24: Confidence interval for 50 tex (Tenacity).

Four ply

Twist of four ply yarn [m^{-1}]	Average value of tenacity [cN/tex]	Minimum confidence interval [cN/tex]	Maximum confidence interval [cN/tex]	Standard deviation
170	17.14	17.02	17.26	0.44
200	17.43	17.31	17.55	0.44
230	18.08	17.92	18.24	0.58
260	18.30	18.18	18.42	0.45
290	18.37	18.24	18.5	0.46